ELECTRICITY METERING AS AN INTEGRAL PART OF AN ENERGY CONSERVATION PROGRAM

By

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B.S.E. Mechanical and Aerospace Engineering, Princeton University, 2004

Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering

in Partial Fulfillment of the Requirements for the Degree of

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AND

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ABSTRACT

Energy management has always been an issue for facility managers, but is now coming under increased scrutiny as businesses become more concerned with greenhouse gas emissions and their environmental footprint. Contemporary research suggests that simply feeding back information on energy use can result in a reduction of consumption between 5 and 20%. The building block of this feedback loop is the energy meter, which is typically standard equipment in homes, but not always installed in commercial buildings, particularly large corporate campuses. Since energy meters have been treated as an added cost in the past, they are not as widely deployed as energy managers would like. However, an analysis of electricity rate structures and hourly electricity use patterns can help identify which buildings provide the shortest payback period for electric meter installation. Raytheon Missile Systems in Tucson, Arizona was able to identify five buildings with a simple payback of under one year, 19 buildings with a positive NPV over two years, and 48 buildings with a positive NPV over 10 years for electric meter installations. Energy meters also provide immediate feedback on usage, verification of utility bills, and the ability to understand peak demand. As a part of an energy conservation program, energy meters are often overlooked, but are a critical building block for data gathering, monitoring, and feedback.

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Next, I would like to thank Yuliya Frenkel, Rich Mendez, and Lang Lawrence for putting together an energy focused internship at Raytheon Missile Systems in Tucson, Arizona. Without much of a precedent, it was a challenge to exist in a state between summer intern and full-time employee, but everyone at RMS helped out to make it happen. I also want to Lang Lawrence, Pat Walsh, and Karen Tempkin for providing a welcoming atmosphere at Raytheon Missile Systems and for introducing me to the Sonoran desert. They were always ready with advice on gas pipelines, electric chillers, and good places to eat. I also want to acknowledge the enthusiasm and energy that Paul Kramkowski and Randy Rogers-Gardner brought to the energy conservation and sustainability teams at Raytheon.

Third, I would like to thank my advisors, Sarah Slaughter and David Hardt for their support for a new field of LGO internships in the energy and sustainability area. I would also like to thank Patty Eames for ensuring that we all successfully navigate the never-ending set of requirements to earn two degrees in two years.

Last, but not least, I would like to thank my family, for always being supportive of my endeavors, and my future wife, Katie, for putting up with the long hours at the office and for spending two years on the other side of the country at this place called MIT.

Biographical Note

David J. Follette was born in Moraga, California and could not stop taking things apart as a child. He soon found himself at Princeton University getting a degree in Mechanical and Aerospace Engineering and designing radio-controlled cars that drove in formations for his senior thesis. After graduation, David tried his hand as an entrepreneur and worked with a few classmates to design a "stair-climbing suitcase" and bring the product to market. Soon after, David moved to Japan for a year on a Fulbright scholarship and studied at Kyoto University designing a gearbox and final drive for the Formula Japan SAE collegiate competition. Upon returning to the U.S., David worked for almost three years at a startup in San Diego as a mechanical engineer designing drive systems for hybrid electric transit buses. Wanting to better understand the interaction of business and engineering, David began the Leaders for Manufacturing (now Leaders for Global Operations) program in June 2008. He completed his internship at Raytheon Missile Systems in December of 2009 and is now looking to continue his career in the area of alternative energy power generation.

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1 Chapter 1: Introduction

Energy is an increasingly important resource and a necessity of the developed world. Without energy, we are unable to keep ourselves warm in the winter, cool in the summer, and enjoy modern technologies.

Unfortunately, energy production has a number of negative externalities, from air pollution to greenhouse gas formation to international conflict. According to John Eggink's research, "Powerplants are responsible for more than a third of the US CO_2 emissions. In 2003, the electric power plants in the US created more CO_2, 2,279 million metric tons, than the transportation sector at 1,874 million metric tons."[1] Since energy is such an integral part of our lives, we are torn between trying to reduce emissions and giving up the standard of living that we gain from energy use. However, if we are able to reduce waste and use energy more efficiently, perhaps we can stretch our existing supplies and even reduce our overall usage.

Generally, there are three approaches to reducing energy use. First, "conservation" involves simply using less energy, and typically involves some kind of sacrifice (e.g. turn down the thermostat and wear a sweater). Second, "efficiency" requires updating older devices with newer technology to use less energy per unit of utility, typically requiring an upfront capital investment. Third, "waste reduction" involves examining how energy is being used and eliminating wasteful energy use. Examples include heating, cooling, or lighting unoccupied buildings, and idling car engines. While the first two options have the negative aspects of reducing quality of life and requiring upfront costs, the third is not only free, but holds vast opportunity.

This thesis explores the potential for "waste reduction" as the cheapest and easiest method to reduce energy use. Energy is very difficult to see and has become so reliable that it is easy to forget

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[1] John Eggink, Managing Energy Costs, Lilburn, GA., The Fairmont Press, Inc, 2006, p101.

where it comes from and how it is produced. It is not that individuals want to waste energy, but for the most part, they are simply not aware of how they are using energy. This thesis looks at the best way to collect information on energy use, specifically electricity, and how to provide feedback to users with the goal of showing them where the waste is occurring. As the old adage goes, "If you can't measure it, you can't control it."

2 Chapter 2: Literature Review

2.1 Strategies for reducing energy waste

The reduction of wasted energy comes as a result of changes in the way energy is used at the infrastructure level or changes in the way energy is used at the personal level. This can either be through an improvement in the efficiency of machinery or a change in the behavior of how devices are used. Motivating those changes requires some kind of feedback of information about how much is being used and a comparison to some reasonable standard of consumption. Obtaining basic usage information requires hardware for data collection, which is typically some kind of energy meter. This chapter looks at each of these strategies, working backwards from behavior change through feedback and efficiency improvements to energy metering at the residential and commercial levels.

"There is no cheaper, cleaner power than power you don't have to produce.

Gary Zarker, former superintendent, Seattle City Light"[2]

2.1.1 Feedback & Behavior Change

Feedback, the process of analyzing the results of an action before repeating that action, is a very important tool that is used in everything from robotic sensors to employee performance reviews. In business, feedback is used to improve processes, both in organizational and operations settings. In the context of energy conservation, feedback is the process of returning energy use information back to the users so they can make more informed decisions about how they are using energy.

In the factory, it is easy to "see" an inefficient process because there will be large inventories of raw materials, finished goods, work-in-progress or defective parts. With some resources, such as water, if there is a leak in the pipe, the floor is wet, or a building is flooded. However, energy waste is

[2] John Eggink, Managing Energy Costs, Lilburn, GA., The Fairmont Press, Inc, 2006, p236.

much more elusive. If the lights are left on all night, there is no damage to the building, and there is no evidence in the morning. Similarly, if a back room is being chilled to 55 degrees in the summer or heated to 85 degrees in the winter, no one will notice unless they visit the room and take the initiative to change the thermostat. Even more elusive are situations where the air conditioners and heaters are on simultaneously, still maintaining room temperatures at the appropriate levels, even though they are using significantly more energy than necessary.

Since energy consumption is difficult to "see", the only reliable measurement method is through metering, which is the same method that utilities use for billing. Unfortunately, utilities typically only provide bills on a monthly basis, and typically in units that are unfamiliar to the average consumer. Willett Kempton and Linda Layne provide an example of what food shopping would be like if it were billed like electricity: "consider groceries in a hypothetical store totally without price marking, billed via a monthly statement like 'US$527 for 2363 food units in April. How could grocery shoppers economize under such a billing regime?"[3] The problem is that the present feedback for electricity use is only once per month and all of the usage is aggregated. Usage for individual appliances, for heating and cooling, and baseline usage (when everything is "off") are not separated. In addition, the measurement unit is kilowatt-hours, which are not exactly intuitive to the layperson. While residential customers could go out and read their meters and take detailed data to try to figure out all of these parameters, it would take a significant amount of labor. Conversely, gasoline, another energy resource that we use frequently, is on the forefront of our minds. Most people can tell you not only the current price of gasoline, but which station in town has the best price. In addition, they would know how often they buy gas, and roughly how much they are paying. Somehow, home utilities (electricity, natural gas, and water), with their ease of consumption are much less visible and similarly, receive less attention.

[3] Willett Kempton and Linda L Layne, "The consumer's energy analysis environment," *Energy Policy*, 1994 p857

Individuals in commercial and industrial settings typically receive even less feedback on energy consumption. First, many buildings and factories have one meter for a very large space and it is locked in a mechanical room, or located in a substation that serves thousands and thousands of employees. The energy bills typically go to the facilities department and the costs are spread out over the whole business. Even if every individual could see the bill himself, it would only have monthly usage information for the whole company, which does not really reflect the usage patterns of that individual.

The feedback challenges of energy information have been well researched over the last thirty years, and researchers have also completed numerous studies examining the effects of different forms of information feedback. Sarah Darby of the Environmental Change Institute at the University of Oxford took an inventory of energy use feedback studies and found that direct feedback to individuals about their home's energy use yielded at least a 5% reduction in energy use, with up to 20% reductions when coupled with an in-home display, pre-paid electricity billing, and an estimate of the cumulative cost of operating specific appliances.[4] Sarah Darby reviewed the published literature again in 2006 and concluded that direct feedback where consumers had easy access to instantaneous energy use information resulted in a 5 to 15% energy use reduction. She also found that indirect feedback, which typically means a monthly electricity bill with suggestions on ways to save energy, can result in savings of 0-10%.[5]

The Electric Power Research Institute (EPRI) in the US has also examined the effectiveness of feedback on residential users. EPRI found that across the literature, feedback was found to result in

[4] Sarah Darby, "Making it obvious: designing feedback into energy consumption" 2001.
[5] Sarah Darby, "The effectiveness of feedback on energy consumption," *Environmental Change Institute,* University of Oxford, 2006, p3.

a range of savings, from negative values to positive 18%, depending on the type of feedback method used. EPRI also listed the key factors in implementing effective feedback, below:[6]

- It is provided frequently, as soon after the consumption behavior as possible.
- It is clearly and simply presented.
- It is customized to the household's specific circumstances.
- It is provided relative to a meaningful standard of comparison.
- It is provided over an extended period of time.
- It included appliance-specific consumption breakdown (some studies).
- It is interactive (some studies).

Although most studies have focused on the residential market, some have looked at large organizations and found significant savings effects from energy information feedback. Siero, Bakker, Dekker, and van den Burg studied a metallurgical factory and measured the number of "energy wasting behaviours" over the course of their intervention program. The program included information on how to save energy and gave weekly feedback on the number of "energy wasting behaviours" observed. This study also examined comparative feedback and included two groups, for which one of the groups was given feedback only on their own performance, while the second group also received feedback on their performance *relative* to the first group. The results show that feedback alone resulted in a 50% reduction in leaving the lights on, but the addition of comparative feedback resulted in a 67% reduction in the same "energy wasting behaviour".[7] Clearly, feedback can have a significant effect on behavior change, particularly with regard to reducing energy waste, and can be even more effective when combined presented as relative feedback.

Professor Sanjay Sarma and his student, Austin Oehlerking, took a similar approach to providing feedback on electricity use to students in an MIT dorm. The study had two goals, first to build and install an inexpensive energy metering system, and second, to provide feedback to the students that

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[6] EPRI, "Residential Electricity use Feedback: A Research Synthesis and Economic Framework", p3.
[7] Frans Siero, Arnold Bakker, Gerda Dekker, and Marcel van den Burg, "Changing Organizational Energy Consumption Behaviour through Comparative Feedback, *Journal of Environmental Psychology*, 1996, volume 16, p243.

was easy to understand and effective in reducing energy use. One of the key features of their web interface for students was a pie chart showing each individual's use as a fraction of the pie. See Figure 1. The pie chart provides relative feedback among rooms and makes it obvious which rooms are using the most energy. The personalized interface also included a smiley face that was either smiling or frowning, depending on whether that individual's room had consumed more or less energy in the previous day than the average for the dorm. The study also provided meters for individual outlets in each student's room to provide insight into which appliances were using the most energy and when that energy was being consumed. Although the study did not have a long enough duration to observe long term trends in energy consumption, Professor Sarma commented that the information feedback "definitely sparked competition" among the students.[8]

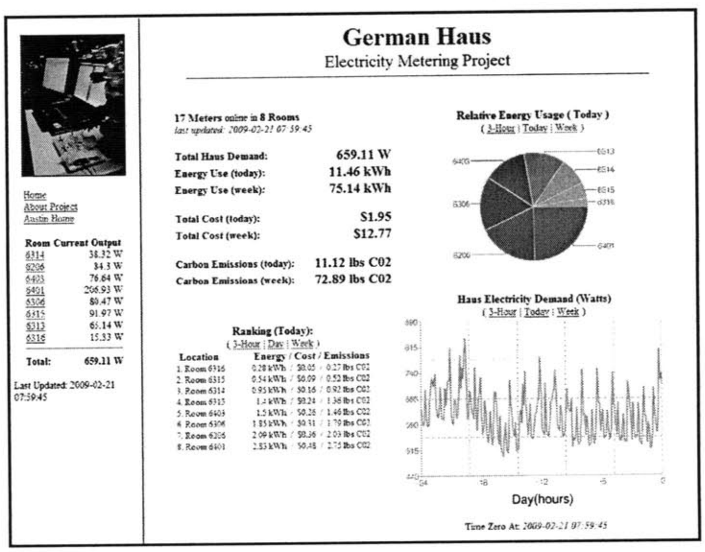

Figure 1: Electricity consumption website from Sarma/Oehlerking study[9]

In another look at building performance, John Eggink cites a United States Department of Energy (DOE) study from the National Renewable Energy Laboratory (NREL), "Case studies have shown that the utility costs can be reduced by 25% or more by identifying energy saving through metering. A less aggressive estimate is approximately 5%." He also shows research from the Lawrence

[8] Teleconference with Professor Sanjay Sarma, September 2009.
[9] http://www.frozeneskimo.com/dormelect/ (no longer maintained as of May 2010)

Berkeley National Laboratory (LBNL) that has found that, "Recent building performance case studies suggest that typical savings of about 15%, and as much as 40% of annual energy use can be gained by compiling, analyzing, and acting upon energy end-use data."[10] While these savings numbers certainly require *acting* on the metering data and probably investing in significant efficiency improvements, clearly there is potential for significant savings resulting from energy usage data.

In conclusion, information feedback of energy data has been widely studied, but not yet widely implemented. The literature suggests definite savings potential from feedback alone, and even greater savings from comparative feedback. In most residential cases, the energy meters are in place to collect the raw data on energy usage, but there is not always a mechanism of converting that data into useful information. In other situations, such as large corporations, there may not even be meters that could provide building-level energy data. These situations would require first gathering the data in preparation for a feedback system.

2.1.2 Energy efficiency

One of the many tools for reducing energy consumption is to use energy more efficiently. As technology improves, appliances are able to do the same work while using less gas, oil, or electricity. A McKinsey report in July 2009 looked at the entire US economy and stressed that energy efficiency alone could provide savings of "9.1 quadrillion BTUs, roughly 23 percent of projected demand, potentially abating up to 1.1 gigatons of greenhouse gases annually."[11] Although the projects that the study proposed were all positive net present values (NPV), each still required significant capital investments to achieve.

[10] John Eggink, Managing Energy Costs, Lilburn, GA., The Fairmont Press, Inc, 2006, p73.
[11] Hannah Choi Granade, Jon Dreyts, Anton Derkach, Philip Farese, Scott Nyquist, and Ken Ostrowski, "Unlocking Energy Efficiency in the U.S. Economy, Executive Summary," *McKinsey Global Energy and Materials*, p1.

In terms of energy efficiency at the building level, comparing new buildings with energy efficient infrastructure to those with standard infrastructure can show the savings potential from adopting energy efficient technologies. The US Green Building Council (USGBC), which develops the Leadership in Energy and Environmental Design (LEED) certification program, has documented the energy use characteristics of new buildings certified to their standards and compared them with average uncertified new buildings. For a building to be LEED certified, it typically must include better insulation, high performance windows, energy efficient lighting, and computer controlled HVAC systems. In 2008, they found that buildings that achieved the bottom tier "certified" LEED status used 26% less energy than the average building, "silver" certified buildings used 32% less energy, and "gold/platinum" certified buildings used 44% less energy.[12] Although the USGBC does not include the cost premiums for these buildings, the results do show significant energy savings. An important note is that these results are for newly constructed buildings, where the incremental cost of installing energy efficient infrastructure is relatively small. For existing buildings, the cost of replacing older machinery with new, efficient machinery could be much greater.

2.1.3 Electricity Metering

While information feedback and energy efficiency are each effective methods of reducing energy use, each of these solutions relies on energy usage data. Without a clear pictures of how much electricity is flowing through the wires and how much gas is flowing through the pipes, there is no information to feed back and there is no way to know if an energy efficiency program has actually made an impact on energy use.

For homes and small businesses, the utility companies use their own meters to differentiate usage between separate payers, since each customer should only pay for what he uses. While information about the aggregate use of the home or small business is appropriate for billing, it does not allow

[12] Cathy Turner and Mark Frankel, "Energy Performance of LEED for New Construction Buildings," *New Buildings Institute*, March 4, 2008, p16.

the consumer to determine any greater granularity of *where* or *when* the energy is being consumed. Additional meters are the clear solution to this problem, but consumers and businesses have historically had little interest in paying for this kind of data.

For large businesses, the information situation can be even worse. Large commercial or industrial sites typically pay lower rates for electricity and natural gas because they purchase wholesale quantities at high voltages and high pressures. The utility only meters the energy at the point of sale, and it is up to the customer to determine how to distribute the energy and how to understand how it is being used. Similar to the residential setting, there has been little incentive in the past to install meters that are not for billing purposes, so a business could have hundreds of buildings and thousands of users all connected to the same meter. Thus, when trying to promote energy conservation or efficiency within any sub-section of the business, it is almost impossible to quantify any discernable difference in the aggregate energy consumption.

Similarly, it can be very difficult to quantify any localized reductions in energy consumption when there is no way to separate it out from the consumption the whole business. In a study of non-energy intensive manufacturing companies in Sweden, P. Rohdin, and P. Thollander found that one of the primary barriers to energy efficiency measures is that "a particular department does not receive any of the profit from an efficiency measure." Respondents also noted that "a prerequisite for allocating the profit from an energy efficiency investment is equipment that can measure the change," and "...the largest problem with implementing energy efficiency measures, is the fact that I have hardly any metering equipment...."[13] As we will see in the case study, Raytheon Missile Systems has a very similar problem with wholesale electricity purchasing and difficulty quantifying how energy is being used (or saved) in sub-sections of a large industrial campus.

[13] P. Rohdin, P. Thollander. "Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden," *Energy 31 (2006)*, p1841.

In conclusion, behavioral change, information feedback, and energy efficiency are all very important tools to reduce energy use. However, since each of these methods relies on energy usage information, the first step in the process of energy use reduction is to begin to collect data on energy consumption by installing energy meters.

2.2 Electricity metering in other contexts

With a growing popular interest in energy consumption, (perhaps as a result of Al Gore's movie about global warming, *An Inconvenient Truth*), individual consumers have become more involved in understanding their energy use patterns. As a result, there are now a number of consumer products that allow individuals to take a closer look at their own energy consumption at home. The range of metering products measure energy at different levels throughout the home and give some examples of how businesses may want to meter their usage as well.

Of the products I have seen on the market, the most basic is the digital electric meter that plugs into a wall outlet and measures the power consumption of an individual appliance. Although it is not capable of projecting usage over time, it does provide instantaneous power flow and totalizes energy consumption. A popular example is the "Kill-a-Watt" meter from P3 International. See Figure 2, below. While the "Kill-a-Watt" meter only provides data on one appliance at a time, the feedback is instantaneous and clear to the user.

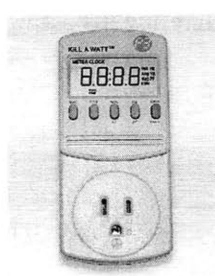

Figure 2: Home energy meter: Kill-A-Watt from P3 International[14]

[14] http://www.p3international.com/products/special/P4400/P4400-CE.html

One step up from a single outlet meter is a whole-house meter. Black and Decker sells a product that uses an optical eye to count the number of revolutions of the wheel on a home electric meter and wirelessly transmits that information to a display in the home. It does not require any electrical skill to install and it gives instantaneous feedback on the power consumption for the whole house. In addition, it is also able to predict the monthly total energy use and the monthly bill, based on the pricing structure entered by the user. See Figure 3, below. While this product does not provide the granularity of the Kill-a-Watt, it still gives instantaneous feedback and can provide consumption information in dollar units, which are much for user friendly than kilowatt-hours.

Figure 3: Black and Decker home Power Monitor wireless display[15]

After researching the effectiveness of energy feedback, I was curious whether information feedback would have the same conservation effect in my own home. As an experiment, I purchased the home power monitor, and I ultimately made changes to the way I use electricity.

One of the first readings that I wanted to determine about my home was "baseline usage" or the power being used when everything is "off". When I read the meter immediately after waking up in the morning (before turning on any lights), I found that it registered 0.1kW, or 100W. Since the meter's resolution is 0.1kW, this seemed to be a reasonable amount of power as a base load. However, after turning on the lights in the kitchen, the power consumption jumped up to 0.7kW, a

[15] http://www.blackanddecker.com/Energy/products.aspx

600W jump. I was appalled that turning on two switches could result in that much power usage. (One switch controlled 4x75W recessed lights, and the other controlled a chandelier with 5x60W lights) Within a week, I had replaced all of the lights with compact fluorescent lights (CFLs) and reduced the 600W load to 150W. While it would have been possible to determine the energy use from the lights without the power monitor, the real-time information feedback provided a clear link between cause and effect that made the case for CFLs very compelling.

One step beyond the home power monitor are the products that collect detailed consumption data and are able to store it on a computer for additional analysis. Many of these products interface with a home automation system and some interface with Google's power analysis software, *Google PowerMeter*. These systems are similar to what commercial customers and industry would install, and provide minute-by-minute consumption information as well as forecasting. The only downside is that these products are typically more expensive and need to be installed within electrical panels by an electrician. However, the quality of data is significantly better from this type of installation, and ideally, it would be installed when the home is built. See Figure 4 and Figure 5, below for images of the TED 5000 hardware and Google PowerMeter's software solutions for energy usage information feedback.

Figure 4: The Energy Detective (TED) 5000 home power monitoring hardware

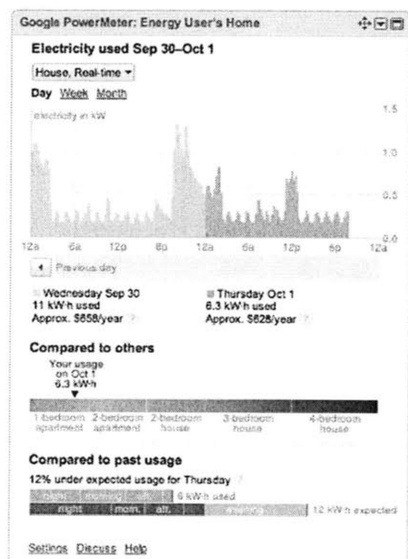

Figure 5: Google PowerMeter web-based dashboard[16]

2.3 Conclusions from literature

1) The most inexpensive strategy to reduce energy consumption is to eliminate waste

2) Two proven tools to reduce waste are information feedback with behavior change and energy efficiency

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[16] http://www.theenergydetective.com/ted-5000-overview.html (Accessed 2/2010)

3) A critical aspect of feedback and behavior change is information. In addition, energy is impossible to "see" so energy meters a critical part of the process.

As energy meters are the first step in the process of energy conservation and they require a capital investment, there must be a clear justification of where meters should be located. Although energy meters clearly provide value, quantifying their value and understanding where they can provide the best return on investment is the goal of the following case study on Raytheon Missile Systems in Tucson, Arizona.

3 Chapter 3: Case Study of Raytheon Missile Systems, Tucson, Arizona

3.1 Background on Raytheon Missile Systems

Raytheon Missile Systems (RMS) is one of the six major business units of Raytheon Corporation. RMS has offices in Alabama, Arizona, California, Kentucky, and New Mexico. Tucson, Arizona is the largest site within Missile Systems and was the location of my six-month internship. The Tucson branch of RMS employs approximately 12,500 people over four major sites. I worked at the largest of the four, named the "Airport Site" because of its proximity to Tucson International Airport. Roughly 10,000 people work at the site, spread out over 50 buildings and three million square feet of office, manufacturing, and laboratory space.

RMS was Hughes Missile Systems until 1997 when it was acquired by Raytheon and renamed Raytheon Missile Systems. RMS now owns the business, but the land and much of the infrastructure is on lease from both the US Air Force and Tucson International Airport.

3.2 Raytheon motivation for energy conservation and sustainability

Raytheon Corporation has a history of energy conservation and sustainability dating back to 1999. Raytheon has been a member of the EPA Climate Leaders program since 2002, and joined the US EPA's Energy Star program in 1999.[17]

In 2002, energy managers from all six Raytheon business units began a dialogue and best-practice sharing that has become the "Enterprise Energy Team." This team has representation from each of the business units and meets regularly to set yearly goals for energy reduction for each business unit and the enterprise as a whole.

At the business unit level, both the Facility Services and Environmental Health & Safety (EHS) departments champion different portions of greenhouse gas reduction and sustainability. EHS

[17] Raytheon Stewardship Report 2004.

handles waste management, from hazardous waste to recycling, and reporting of greenhouse gases and other pollutants to government agencies. Facility Services is responsible for the construction, operation, and maintenance of buildings and initiates many of the efforts to upgrade technology and change behavior to reduce energy usage.

3.3 Energy conservation to date

Over the last several years, Facility Services has made many significant upgrades to the site to reduce utility costs and reduce emissions. First, they have an extensive building automation system (BAS) that monitors and controls almost all of the HVAC systems throughout the airport site. This level of measurement and control allows them to adjust temperatures based on occupancy, time of day, and season, all from a central control center. Unfortunately, it is not well connected with the electricity metering system, so they are not able to change the climate control based on energy demand or pricing.

RMS has also invested in a number of strategies to reduce their peak electricity demand. As RMS pays $19.02 per kW[18] of peak demand, there is significant savings potential for a site that can have peaks as high as 20 MW during the summer months. One strategy is to take advantage of the backup power generators that exist on-site and use them to supply supplemental power during the peak times of the day. Unfortunately, this requires burning diesel fuel or natural gas, and while it may save money for RMS, in a global sense, it does not necessarily change the production of GHGs or reduce emissions.

Another strategy that reduces peak demand and GHGs and emissions is the use of a thermal energy storage (TES) system. As Tucson, Arizona has an average of 3,017 cooling-degree-days per year (compared to 777 in Boston, MA), and 100F+ temperatures from May through October, air conditioning equipment is a significant consumer of electricity. RMS has installed two thermal

[18] TEP Rate Structure LLP-14 Large Light and Power Service

energy storage systems, which are essentially large water tanks that store chilled water, produced during the off-peak evening hours, and then provide the chilled water to cool buildings during the middle part of the day. This allows the high power chilling units to operate during the off-peak times, reducing demand, and to operate at higher efficiency by exchanging heat to a cooler ambient temperature in the evenings. While not all buildings at the site are currently connected to a TES loop, as buildings are retrofitted, they are integrated into the system.

During 2009, RMS also hired an outside consulting service to enact behavioral change at the site. The consultants started a program that included maintenance repairs, lighting analysis, HVAC analysis, and energy awareness. The behavior change aspect focused on energy audits to ensure that lights and devices were turned off at night. The consultants also developed a spreadsheet to estimate the energy use of each building, based on the electricity meters that were available to be read, and the type of activity in the building. They delivered a weekly report to show the change in energy use, and ultimately were able to deliver on their promised energy conservation goals.

3.4 Energy conservation strategy and motivation for increased metering

RMS has completed numerous projects and initiatives to reduce electricity consumption, and they continue to do so. However, there are recurring issues with each project that could be solved with better data collection and analysis.

One of the key problems to date has been the inability to quantify the actual energy savings from any of these projects or initiatives. Although it is typical to approve projects based on estimates, there is rarely the time, hardware, or manpower necessary to follow up after the project is complete to measure the effects. While this step in the process is not critical to saving energy, it is critical to proving that energy saving projects are economical, and continuing to receive investments in energy saving measures.

Second, the behavior change methodology thus far has been a "command and control" method of informing people of their non-compliance with energy policy. A more inclusive approach would be to share energy consumption data with those who control energy usage and encourage them to come up with energy conservation solutions on their own.

Lastly, the energy profiles for individual buildings that the energy conservation consultants created were primarily "best guesses" and estimates of how the buildings used energy. Without any type of detailed meters (or meters on the buildings at all), there was no historical data, no baseline, and no way to measure change. Ideally, the building would have separate meters for lights, plug loads, and HVAC equipment, but at the least, a dedicated meter for each building to separate it from the overall site.

The missing piece in each of these situations is data. Unlike inventory or work in progress, it is not possible to walk around a factory floor and catalog where the energy is being used and being wasted. Energy, particularly electricity, is being consumed day and night, when people are working and when buildings are vacant. Without energy meters, it is very difficult to understand how energy is being consumed and where it is going.

Since most of the energy consumption at RMS is electricity, one way to solve these issues is to install better electric metering across the plant site. This would allow the separation of energy consumption between buildings and potentially between different types of consumption within the building, depending on the detail level of the meters. Newer electric meters are also able to take data intervals that allow energy managers to see the difference in electricity demand between night, day, and weekends. The focus of the case study at RMS is to examine the selection process for locating electricity meters across the sites in Tucson, and to determine the economics for such an installation project.

3.5 Raytheon Energy Use Analysis

3.5.1 Breakdown of Energy Usage in Tucson, AZ

The first step to reduce energy consumption is to understand how the energy is being used. Since energy comes in different forms (electricity, natural gas, gasoline, etc) a common denominator is necessary to compare different types of consumption. One method of comparison is to convert all energy sources into units of "tons of carbon dioxide equivalent." (Another option is to use cost to compare the various resources, but fuel costs vary over time, and do not accurately represent the relative environmental impacts of energy consumption). In Tucson, the primary energy sources are electricity and natural gas. Figure 6 is a summary of energy use from utility data from 2008. Clearly, the CO_2 production from electricity consumption far outweighs natural gas consumption, which is not surprising, given Tucson's warm climate and limited need for heating.

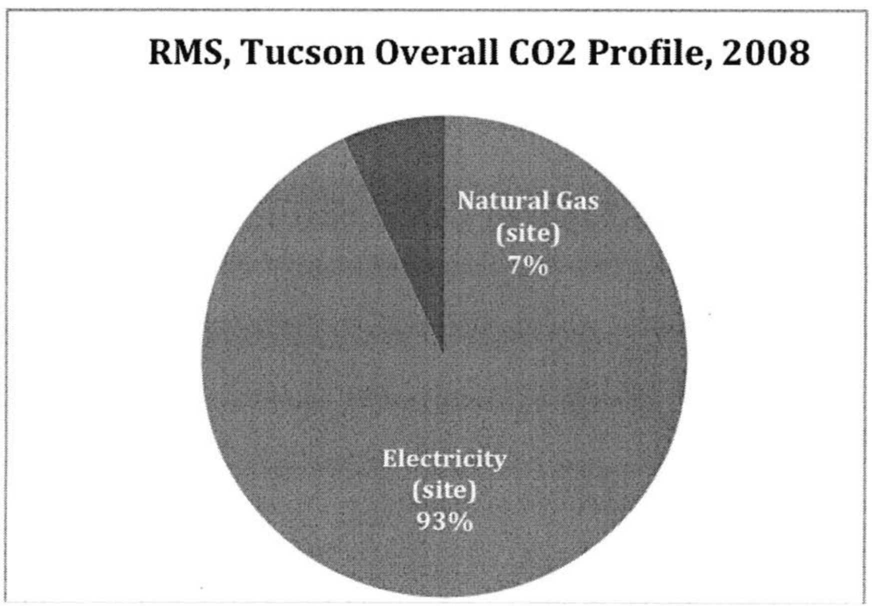


Figure 6: Overall CO2 Profile for RMS, Tucson

The US Environmental Protection Agency (EPA) and World Resources Institute (WRI) classify greenhouse gas emissions as Scope 1, 2, or 3.[19] Scope 1 consists of emissions that are directly created by the organization, such as burning coal to heat a furnace or boiler. Scope 2 consists of

[19] World Resources Institute (http://www.wri.org/publication/content/7712)

indirect emissions, which are typically from the purchase of electricity, chilled water, heated water, or steam. Scope 3 emissions are the remainder, which can include everything from fuel used by employees to commute to work, and the embodied energy used to produce raw materials that are purchased.

The Tucson site of RMS currently only monitors Scope 1 and Scope 2 emissions. Scope 3 emissions are not being tracked, as there is no standard measurement procedure, and it would require significantly more data to calculate. Nonetheless, Scope 3 emissions are probably significant contributors to RMS' overall profile. As an exercise, I made a rough estimate of the emissions from commuting:

Taking an estimate of the number of daily commuters (7,500), their average round trip drive (25 miles), their average mpg (18 mpg), and the average number of days worked per year (225 days), shows that commuting could be responsible for up to 20% of RMS' GHG emissions. (Figure 7)

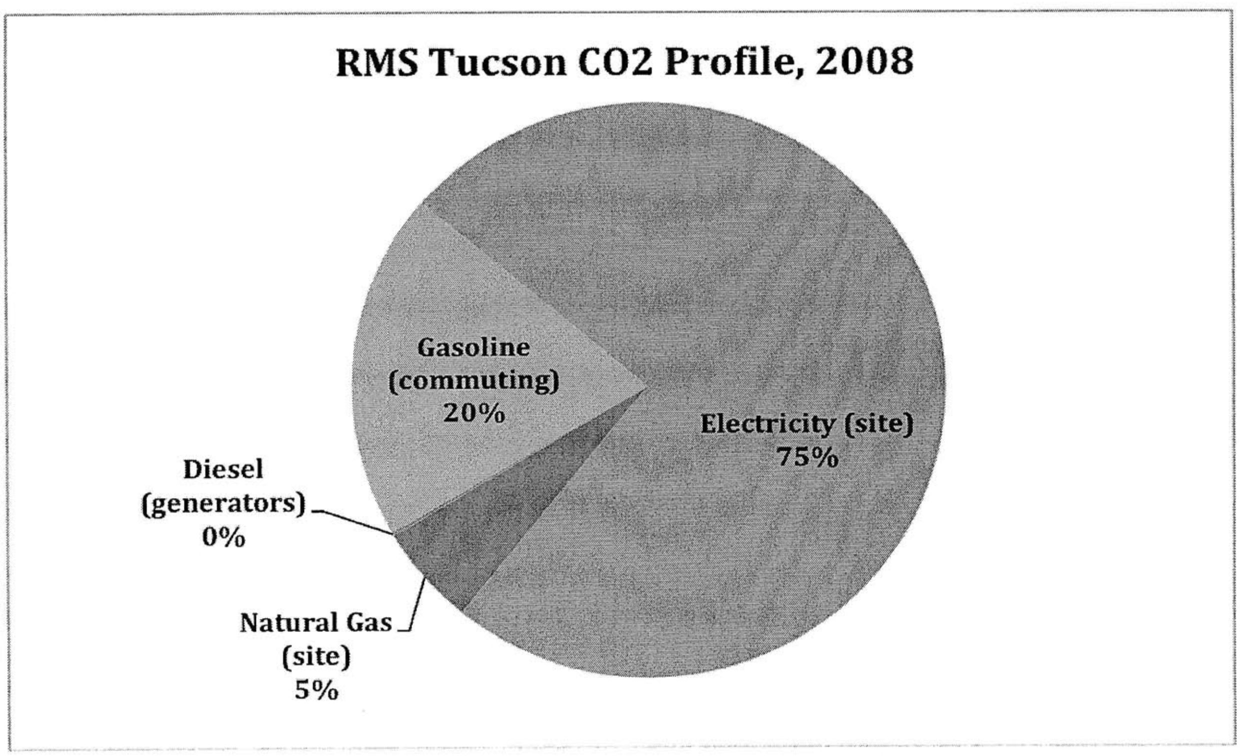


Figure 7: CO2 Profile for RMS, Tucson with Commuting

While the case study in this thesis focuses on the effects of Scope 1 and 2 emissions, it is important to consider the bigger picture and realize the external effects that RMS has the environment as well.

3.5.2 Analysis of present electricity usage

The Airport site, the largest of the four campuses in Tucson, has digital electricity meters installed in its electrical substation, which are capable of reading electricity usage data on a real-time basis. (Although this provides data on the site and for specific electric circuits, it does not provide the necessary information for feedback to building occupants) While detailed meter data is the most valuable, there are important trends that can be seen in the site-wide consumption data. Figure 8 is a graph of electricity use during June 2009 at the RMS Airport site with each data point representing the average rate of consumption for each 15-minute period.

Site-level data provides a high-level view of fluctuation in demand between day, night, weekdays and weekends. From Figure 8, one can discern the five weekdays each week, and the two weekend days. In addition, Fridays typically tend to have lower demand, as RMS works on a 9/80 (9hrs/day for 9 days, making 80 hours) schedule where many employees receive a vacation day every other Friday. On a macro level, it is also possible to see how weather varied throughout the month, as the end of the month was warmer (and required more air conditioning) than earlier in the month.

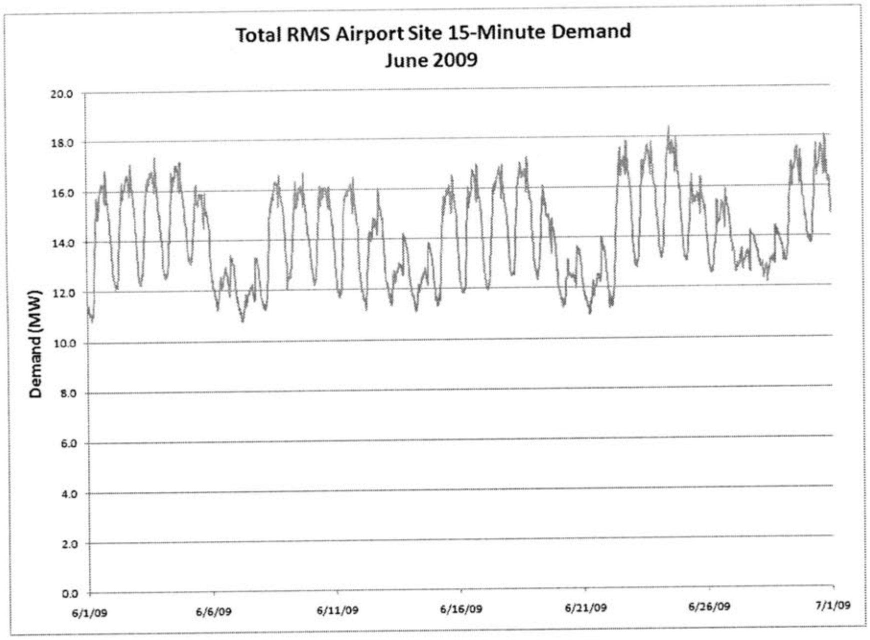


Figure 8: Electricity demand in June 2009 at 15-minute intervals

Table 1 gives a numerical analysis of the demand profile at the airport site, including the peak and minimum demands for weekends and weekdays, and the average demand for each of those periods. Overall, demand at the airport site for June 2009 varied from a minimum of 11.0 MW on weekends, to a maximum of 18.1 MW mid-week, just before noon. One very important aspect of this data is that even at minimum demand, the site still used 60.8% of its peak demand for that month. As there are very few people working during the weekend, this is a surprising amount of energy. As a point of comparison, my home uses 100W or less at a minimum, and can use up to 10,000W at peak. For my house, the minimum demand would be 1% of the peak demand.

	Weekday Demand	Weekend Demand	Overall
Peak	18.1 MW	14.4 MW	18.1 MW
Minimum	11.1 MW	11.0 MW	11.0 MW
Average	14.8 MW	12.5 MW	14.2 MW
Minimum Demand percentage of Peak Demand	61.3%	76.4%	60.8%

Table 1: Demand characteristics for June 2009

Although it is clear that the Airport Site has a constant base load of 11.0MW, which, at 60% of peak load, is very significant, this data alone does not suggest how to solve the problem. With over 50 large buildings on the site, it is not clear which buildings are using energy efficiently and which ones are wasting energy. Unlike defective parts, work-in-progress, and physical inventory, when there are inefficiencies in electricity use, they are almost impossible to see without electric meters. The next step in the process of reducing the base load is installing more meters to determine where the power is going.

3.6 Anomalies in Energy Consumption

The 50 digital meters installed at the Airport site monitor 38 circuits that feed roughly 50 buildings. Although this does not allow separation of each building, it can expose the usage patterns and anomalies, at least at the building cluster level.

Small but significant anomalies in usage are very difficult to see at the site wide level, as noise in the data (1-2%) could be a swing of 200kW. Examining monthly usage graphs for all 50 meters is a very time consuming process and graphing them all on the same graph does not account for the absolute differences in their demands. (Some circuits may consume 1MW regularly, whereas others are 50kW)

One way to rapidly determine which circuits are acting abnormally is to normalize each demand reading from each circuit against its monthly average. Figure 9 shows how normalizing causes two circuits to "jump-out" of relative obscurity in the graph, and show very abnormal usage patterns.

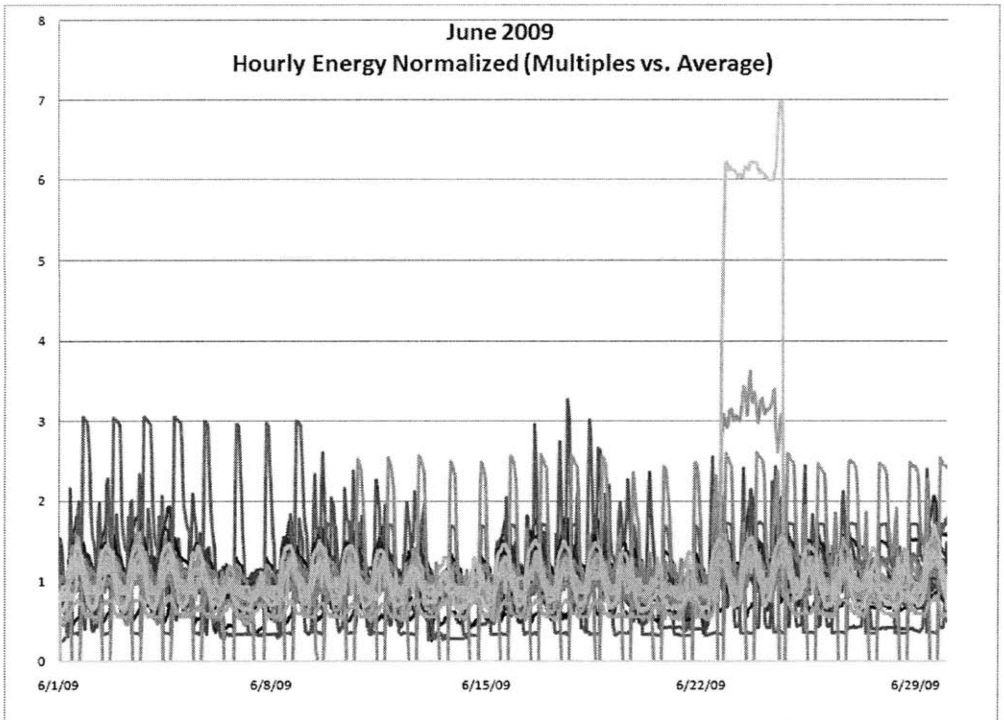


Figure 9: Normalized electricity usage for all meters in June 2009

Since this data is normalized against the average, this is a graph of deviation from the average for each hour over the month of June. Some circuits clearly vary from their average on a regular basis, and some show very flat usage profiles. However, it is clear that two circuits immediately stand out as being abnormal. Although these individual loads are miniscule compared to the usage at the airport site, using six or seven times more than average is cause for alarm. Without metering these circuits separately, however, this anomaly would have been lost in the noise of the whole site.

As it turned out, these circuits contained equipment for treating contaminated water at the Airport site. The equipment had been down for maintenance during the first half of the month, and when they came back online, it was a significant change in usage.

4 Chapter 4: Challenges with energy metering

We have speedometers to show how fast we are driving, gas gauges to alert us to low fuel levels, yet most organizations lack real time gauges to determine energy performance.[20]

Although there is no disagreement that more information on electricity use would be useful and interesting, the information is not free. There is cost associated with the hardware to sense how much electricity is flowing, the software to collect the data from the hardware, the installation cost of the hardware and software, and the personnel time required to determine where meters should be installed, and to analyze the data once it is collected.

Although the literature suggests significant payback from the feedback of energy consumption information to users (in the range of 5-20%), the process of installing meters seems to be a necessary evil of the process. Many studies make use of existing meters (typically in homes) and examine the effects of relaying the data back to users in a timely and useful form. While this is a critical part of the process, in a large business setting, there are not always meters to separate out usage into meaningful divisions. Also, there are not clear answers as to what level of detail provides the most value. Clearly, the more detailed the feedback, the better, but at some point, the cost of the meter will be greater than even the cost of the electricity that it will ever measure. In addition, different buildings and different usage patterns have different amounts of waste and potential for savings. The following analysis walks through three different strategies for data collection and meter placement and examines the effects of each. Chapter 5 looks at the very basic case of manually reading existing meters and feeding back information via manually generated reports. Chapter 6 examines a pilot project to install detailed meters in one section of a building,

[20] John Eggink, *Managing Energy Costs*, Lilburn, GA., The Fairmont Press, Inc, 2006, p72.

and Chapter 7 is a complete analysis of a corporate campus and how to determine which buildings would benefit most from meter installation.

5 Chapter 5: Observed behavior change from manual meter reading and feedback

This first analysis is intended to show how even very basic feedback tools can have a measurable effect on energy conservation. While digital meters on every circuit would have provided more detailed data, simple tools such as a pen, paper, clipboard, and a spreadsheet were sufficient to create meaningful feedback to energy users and begin changing they way they use energy. Unfortunately, this method is fairly time consuming (see Figure 10, below), and probably not sustainable in the long term without an employee wholly dedicated to collecting energy data from meters.

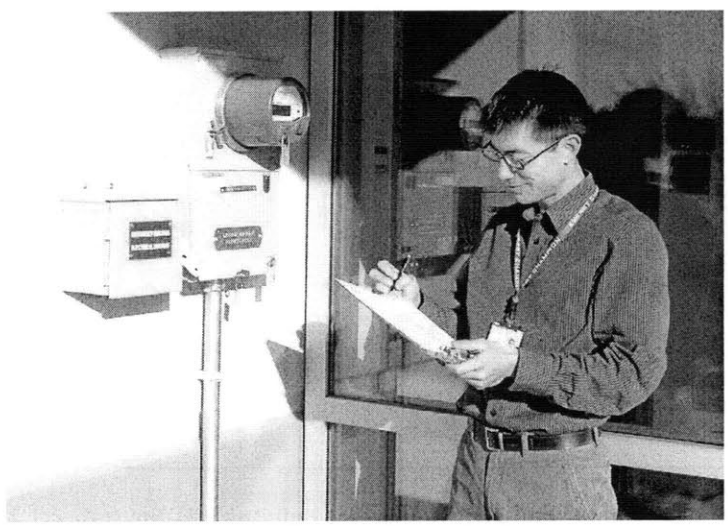


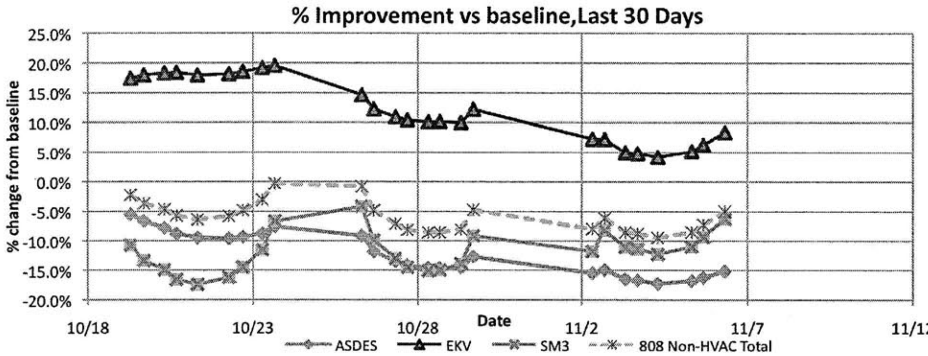
Figure 10: The author manually reading an electric meter at RMS

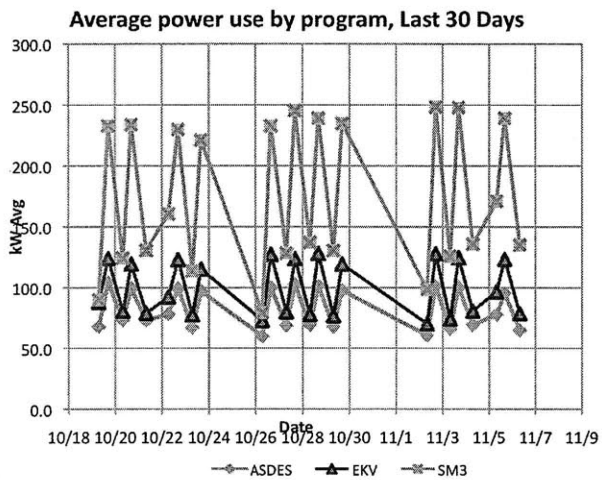
Beginning on September 10, 2009, the five meters of the main feeds to building 808 were read on a daily basis (incidentally, these are the same feeds that were proposed to be digitally metered in the pilot project described in Chapter 6). Just over one month later, I delivered the first "Weekly Electricity Report" to the building energy manager and his building energy partner. Figure 11, below is the last weekly energy report from November 9, 2009. Over the course of the September and October, the reports had a measurable effect on their behavior, culminating in actual energy savings, summarized in Table 2 below.

Weekly Electricity Report

Building 808 – November 9, 2009

Net Change vs. Baseline			
ASDES	EKV	SM3	808 Overall
-15.1%	8.3%	-6.3%	-5.0%





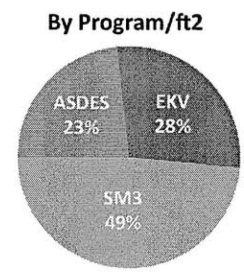


Figure 11: Weekly Electricity Report for Building 808, November 9, 2009

Date	Feedback from Building Energy Owner & Actions
10/19/09	First weekly electricity report delivered. FEEDBACK: Since programs match geographically with electricity distribution, using program names rather than geographic areas (SW, NE, etc) in the report, could be more effective. Questions included, Why can't we see the improvements that we have made over the last month? How much have we improved since last month, last year? Why is weekend usage so high compared to weekday usage? Does usage vary between night and day the same way as weekday and weekend? ACTION: Building energy manager and partner began reading electric meters in morning and evening to separate out nighttime usage.
10/26/09	Second weekly electricity report delivered
10/27/09	FEEDBACK: Energy partner notices that nighttime energy use is unacceptably high and suggests an off-hours hunt for power users. Communications closets suggested as trouble areas.
10/28/09	ACTION: I check the temperatures in the communications rooms through the building automation system. A normal temperature for a communication closet is 68 degrees or higher. One of the rooms is reading 57 degrees.
11/9/09	Third weekly electricity report delivered
11/9/09	ACTION: Building energy owner wants to setup a meeting to brainstorm where the energy may be being used at night
11/12/09	ACTION: Meeting with building energy owner. FEEDBACK: Meter reading is too time consuming and hazardous (navigating in and out of electrical rooms) for regular employees. The building usage looks relatively constant, and additional data is not useful until there was a plan to make an energy saving change.
11/19/09	ACTION: I visited each communications room and found large holes in the ceiling allowing cool air to pour into the return air plenum – the closets were cooling the building!
11/20/09	Filed work orders to fix the broken ceiling tiles in two communications rooms in Building 808.

Table 2: Summary of results from feedback of electricity usage data

Although manual meter reading is tedious and requires significant manpower, it fulfills three of the important criteria outlined by EPRI for effective meter feedback: (1) "It is provided frequently, as soon after the consumption behavior as possible", and (2) "It is customized to the household's specific circumstances", and (3) "It is provided over an extended period of time".[21] Before the weekly energy report, the only information available about the building's energy use was from outside consultants estimating the weekly use from larger meters on-site, or monthly usage information for the whole three million square foot campus. Now, there was credible data, collected by RMS employees, with daily (and some twice daily) granularity, covering four areas of approximately 40,000 square feet each.[22]

Secondly, the weekly electricity report increased the demand for detail in the information. In the RMS case, the building energy owner decided that he and his energy partner would put in their own effort to read the meters twice each day. Adding this data to the report required little additional analysis yet gave more information on daytime and nighttime usage. As digital meters come online for building 808, I am sure that they will be monitoring energy usage on a real time basis.

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[21] EPRI, "Residential Electricity use Feedback: A Research Synthesis and Economic Framework", p3.

[22] Although five meters were read, four of them served office spaces while one of them served the central heating and cooling plant.

6 Chapter 6: Determination of the value of detailed sub metering

Even though the meter itself does not directly save energy, the information gleaned from the meter, when acted upon, can produce substantial savings. Information is a powerful tool, what gets measured gets managed.[23]

While manual meter reading for building 808 gave an effective overview of energy consumption for portions of the building, it was unable to answer the question "Where is the energy going?" Without more detailed metering, it was nearly impossible to pinpoint what devices in the 40,000 square foot area were using the most energy and whether they were using it efficiently.

Some studies have shown that metering detail can increase accountability and make feedback more effective, but these studies are have generally been completed at the residential appliance level. For energy managers overseeing office space for a business, separating out lighting, plug loads (computers) and climate control (HVAC) is not only valuable to determine how energy is being used, it can also serve as valuable data when proposing technology upgrades or machine replacement.

Ideally, there would be a meter on every single device. However, since meters come with a cost, businesses must decide what level of meter granularity provides the greatest energy savings at the least cost.

6.1 Pilot project motivation

As RMS expands its electric meter network, it is important to install them at a level of detail that provides the best return on investment. Intuitively, the data becomes more interesting as it becomes more detailed, but there is also an increased cost to adding detail. Much of the literature

[23] John Eggink, Managing Energy Costs, Lilburn, GA., The Fairmont Press, Inc, 2006, p73.

around metering has focused on residential customers, who have a meter on their own home, which links both an individual building, and an individual payer.

The literature shows that the link between the usage and the payer is critical, and there has been little research into the value of metering below this level. A study by Kate Walter in the *Journal of Property Management* cites water consumption reductions of 25 to 40% when residents pay for water and sewer costs based on their own submeter, rather than being charged a fraction of the total usage through a larger meter.[24] Studies looking at electricity metering for apartment complexes have had similar findings: "master-metered complexes tend to consume about 35% more energy than individually metered sites."[25] Therefore, meters should definitely be placed at the building level, preferably, at a level of accountability, but possibly at a level of greater granularity to determine how utilities are being used. Without strong recommendations from previous research, I developed a pilot project to test different levels of meter detail and find actual savings results.

The goal of the pilot project was take a typical office building and determine whether metering down to the cubicle level provided sufficiently greater energy savings to overcome the cost of the additional meters.

6.2 Pilot project building selection criteria

Building 808 and specifically the northwest quadrant of Building 808 were chosen for the pilot project for a number of reasons. First, the office space in this building is very similar to many of the office spaces across RMS. In addition, since the office space within the building is homogeneous, the pilot project could be reduced in size to only a fraction of the building, as results could be

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[24] Kate Walter. "Submetering. Reducing Costs to a Trickle." *Journal of Property Management.* March/April 1997. P25.

[25] Loren Lutzenhiser, "Social and Behavioral Aspects of Energy use," *Annual Review of Energy and the Environment*, November 1993, Vol. 18, p257.

extrapolated to the whole building, and then to other office buildings. This building is also wired in a way that separates loads geographically and by function. Not all buildings separate out the HVAC, lighting and plug loads, so this made building 808 a good candidate for detailed metering.

Another benefit of the northwest quadrant specifically was that the occupants of that space were not scheduled to change offices during my six-month internship. The occupants of the southwest and northeast were scheduled to relocate, which would have made baseline data very difficult to obtain. Lastly, the manager responsible for the energy use of the building and his energy conservation volunteers all reside in the northwest corner of the building. Since they have been instrumental in promoting energy awareness in the building, they were the best candidates to be the first to receive detailed energy use data.

6.3 Pilot project overview

Building 808 has a footprint of 159,000 square feet and has a capacity of up to 400 people. This building receives its power from five main feeds, which conveniently separate the loads between four geographic areas and the "central plant", where most of the heating, cooling, and air handling equipment operates.

Figure 12, below, is a satellite view of the building and shows how the power feeds to transformers (T1 through T5) separate the building geographically into four quadrants. Transformer T3 primarily feeds the large chillers and cooling towers that are visible in the image, just above transformer, T3.

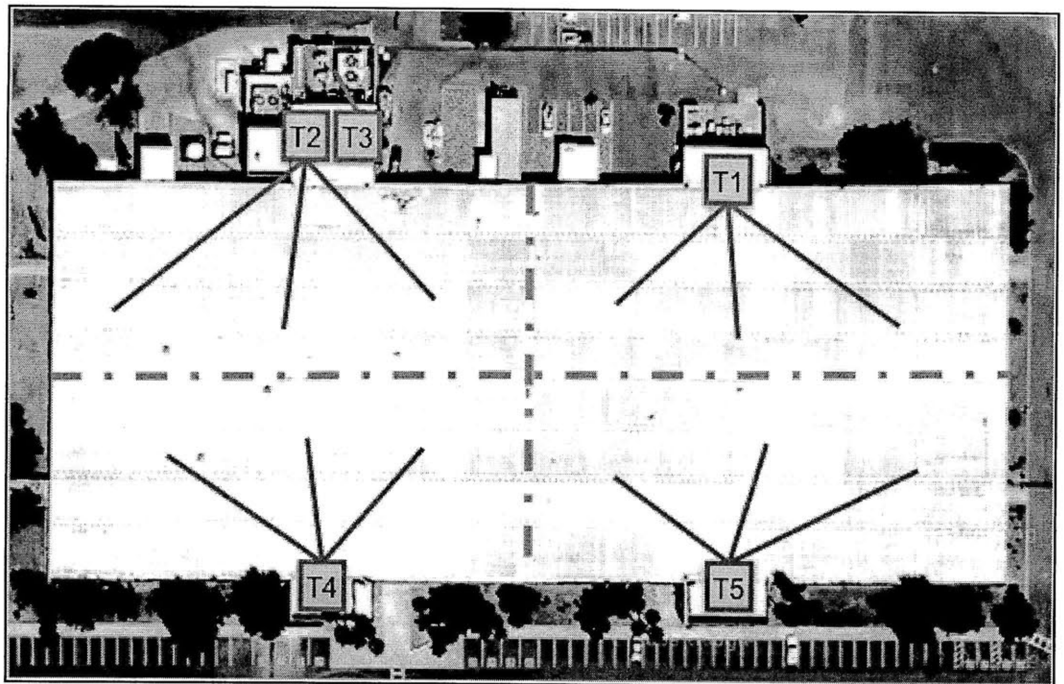

Figure 12: Satellite view of pilot project building with power feeds highlighted

The experiment for this building is to install electric meters at three different levels to determine the value of each different type of data. The first level is to meter the five power feeds and a major branch that feeds a dedicated computer closet. These six meters will allow the separation of this building from other buildings on the same circuit, and it will allow separation of the consumption in each of the four quadrants of the building, the computer closet, and the HVAC systems. These meters will be reading power consumption at the 480V level.

The second level of metering will separate out loads at the 480/277V level, which is typically the voltage for lighting systems and the input voltage to transformers that feed plug loads.

The third level of metering will be at the 208/120V level, which will allow the separation of plug loads geographically, which can isolate groups of cubicles, vending machines, refrigerators, and smaller lighting loads.

This pilot project will include metering at all three levels, focusing on the northwest quadrant of the building. All of the circuits at the second level will be metered, and one branch at the third level will be metered as well. Monitoring these two additional levels will require a total of 15 new electric meters.

Figure 13 is a view of the floor plan of the building, where the stars represent the transformers that feed the lights and outlets in the building. The red arrows give a schematic representation of the power distribution from transformer T2. The centers of the colored circles indicate where the location of the electrical panels and give a rough representation on the outlets that are fed from that panel. The blue circles represent plug loads, generally covering 10 to 15 office cubicles, and the yellow circle represents the lighting panel, which controls the fluorescent lighting for the area.

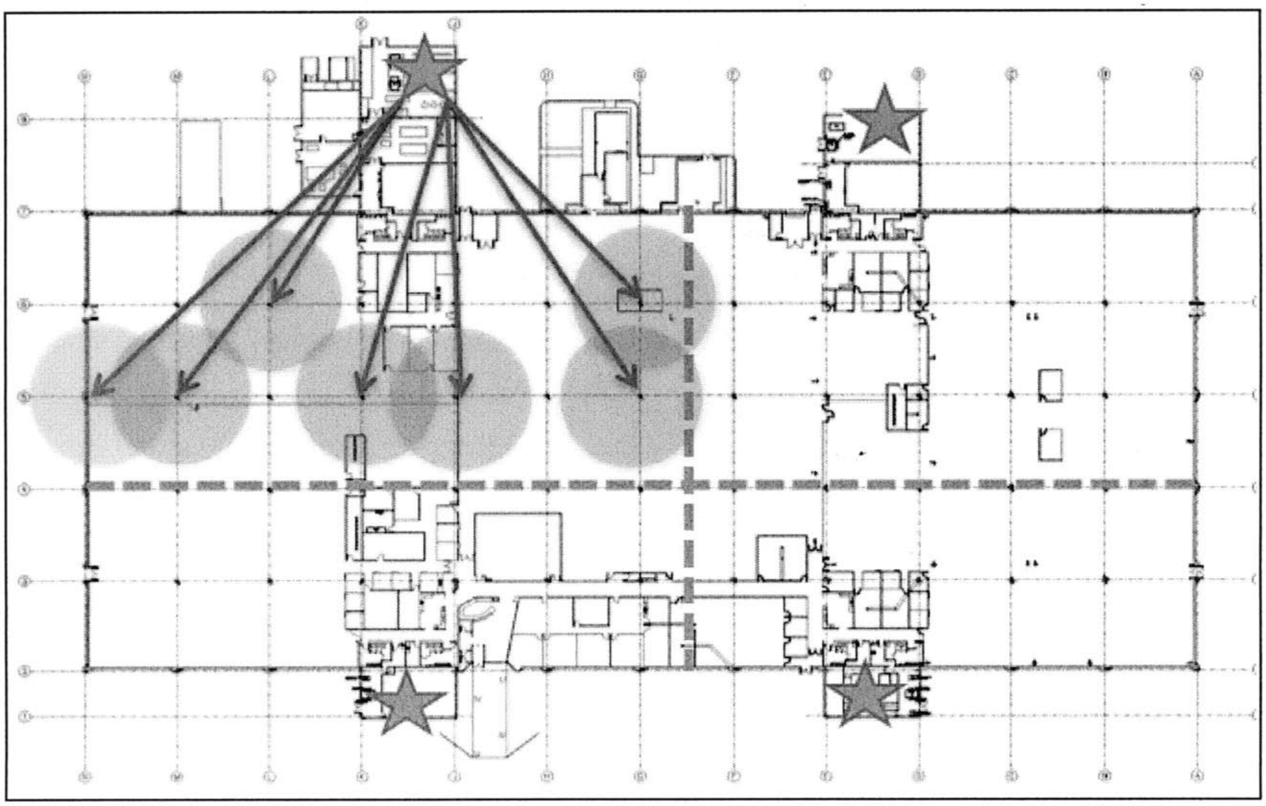

Figure 13: Detailed submetering pilot project diagram

In December 2009 and January 2010, meters for the pilot project were installed on the feeds to building 808 and in the subpanels for the northwest quadrant. The meters were also connected to the new data collection and analysis server, and the system began collecting data in February 2010. See Figure 14, below, for an image of the installed meters.

Figure 14: Installed submeters in building 808

6.4 Recommendations for detailed metering

Unfortunately, the six-month scope of this internship project was not long enough to install meters, establish a baseline, provide feedback, and measure a change. However, the meters are now in place and ready to collect data, so the first step is to establish a baseline. The next step is to determine the actual value of feedback for meters at different levels of granularity. My intuition is that meters provide the most value at the level where different types of loads can be separated (lighting vs. HVAC vs. plug), rather than at the level of groups of cubicles.

Without experimental evidence, I cannot conclusively say that cubicle level meters are not cost effective, but another alternative may be to use temporary meters to understand usage at a high level of detail. Products such as the "Kill-A-Watt" outlet meter cost roughly $20 and can be moved from location to location. For items such as computers or task lights, understanding their usage over a one-minute or one-week period may be sufficient and long term trends may not be as valuable. For these situations, a temporary, portable meter may be the best solution.

7 Chapter 7: Optimizing meter placement to maximize return on investment

Broadening the scope to a whole corporate campus, the next analysis was to determine where to begin installing meters on a site with over 100 large buildings. Without results from the pilot project in Chapter 6, it is still unclear what level of metering detail is most optimal, but under the assumption that at the minimum, each building needs its own meter, it was possible to compare the buildings on campus to determine which are the best candidates for electric meters.

7.1 Site Selection – Electricity Rates

All of the RMS sites in Tucson purchase power from the local electric utility, Tucson Electric Power (TEP). However, the rate structure is very different between the sites, depending on how the electric service is delivered and metered.

The Airport Site, with a maximum demand of nearly 20MW during the summer, takes power from TEP at 46 kV and RMS maintains its own internal substation and distribution network. As such, the Airport Site falls under TEP's "Large Light and Power LLP-14" rate structure, which has separate tariffs for energy consumption and power demand. This type of rate structure creates a challenge when attempting to determine the value of electricity savings from any kind of conservation or distributed generation project, simply because the time of day when the change in consumption occurs has a significant impact on the savings potential. Per the "Large Light and Power" rate structure, RMS pays \$0.0326/kWh and \$19.02 per kW of peak demand (calculated as an average of the top three 15-minute intervals for the month).[26] Figure 15 below shows a graphical breakdown of how RMS's electricity bill is calculated with this rate structure (without taxes and fees). Generally, half of the monthly electricity cost is based on the peak demand, and half is based on the total energy consumption. While calculating an average cost per kWh by dividing total energy used

[26] TEP Large Light and Power LLP-14 Tariff

by the total bill gives about $0.07/kWh, energy used during the evenings that does not affect the monthly peak has a marginal cost of only $0.032/kWh.

Peak Demand		
18,384 kW		
18,148 kW	$19.02/kW	$345,175
18,020 kW		
Total Energy		
10,205,640 kWh	$0.0326/kWh	$332,703
Total Utility Bill:		**$677,878**

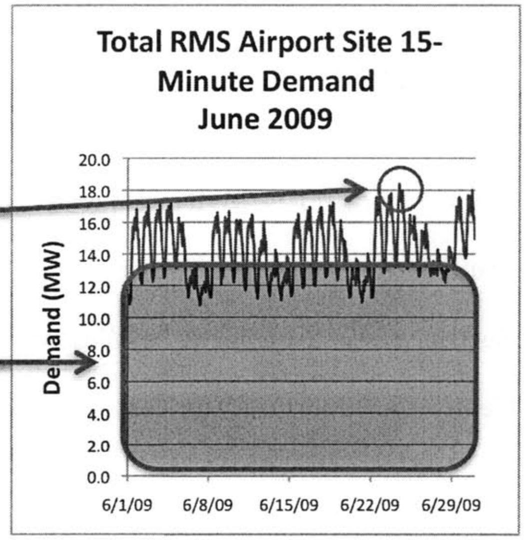

Figure 15: Breakdown of energy and demand charges - June 2009

While some energy conservation efforts, such as turning lights off at night will only affect the energy portion of the bill, more efficient chillers and production equipment will affect both peak demand and total energy consumption. For the following analysis, I used the blended average rate of $0.07/kWh for the Airport Site, although a more detailed analysis could separate out potential savings by their demand pattern to get a more exact estimate of their cost savings.

The RMS site at Rita Road, which is a leased portion of the University of Arizona Science and Technology Park, pays utility bills through the local site management, which is a blended rate of $0.068/kWh, similar to the airport site. Although RMS does not explicitly see the breakdown of energy and demand charges, the demand profile of RMS's energy usage could affect the average rate that they pay to the site management company. In the analysis, electricity at Rita Road was valued at $0.068/kWh, very close to the rate at the Airport Site.

The two smaller RMS sites, "ReyWest" and the "Bike Shop" are both on the TEP General Service "GS-10" rate plan. This rate structure is based only on total electricity consumed (kWh), and is tiered, with the rate increasing significantly for usage over 500kWh per month. For businesses, 500kWh is a very small percentage of their monthly total, and the majority of usage every month falls into the upper tier. At the upper tier rate, Rey West and the Bike Shop are charged $0.116/kWh in the summer, and $0.104/kWh in the winter (before taxes and fees). To simplify the calculations, I used a rounded average of the two of $0.11/kWh for both sites. In terms of savings potential, the cost of electricity is 57% higher at ReyWest and the Bike Shop than at Rita Road or at the Airport Site. Clearly, the opportunity for cost savings should be greater where electricity costs are higher.

7.2 Metering at the building level: Building selection

7.2.1 Building Size and Metered Area

RMS Tucson is comprised of over 200 total buildings, of which 60 to 70 are of significant size to consider metering at all. (Unused guard shacks and small storage sheds are of little interest) The buildings large enough to consider range in size from 8,000 square feet to almost 600,000 square feet. While there is no sliding scale to compare square footage metered and energy consumption data effectiveness, we assume that as the data becomes more detailed, it becomes more effective.

In reality, the most important factor is to link the meter data to a known entity, whether that is a building, an area, an individual, or an organization. On a geographic level, this means having a meter for each free standing building. Within a building, the information is more useful when it can be linked to the lighting system, the HVAC system, or connected to a manufacturing process, or functional group. While this linkage is ideal, existing buildings are not always wired in a way that makes these divisions straightforward. Some buildings are wired geographically, and others are wired based on function, and others, particularly those that have had renovations and expansions, have a mix of the two. Nonetheless, from a quantitative, high-level viewpoint, the square footage metered metric does give an idea of the level of potential detail from a given set of meters.

In attempting to estimate the savings potential for each building and relate it to building size, there is a tension between savings potential and meter value, as buildings get larger. Since the total energy use of each building was estimated by taking an average energy use per square foot for large buildings in the United States, as buildings get larger, estimated energy use increases. Then, since energy savings is estimated as a percentage of total energy use, absolute energy savings increases with larger buildings. However as the metered area of a building increases in size, the metering information becomes less relevant, and the energy savings percentage needs to be decreased to correct for this change. (I use the term "metered area" to define the average area per meter in a building with multiple power feeds and multiple meters.) In order to estimate the savings potential of a given building, both of these factors need to be taken into account.

The limits on metered areas are set to a maximum effective size to 200,000 square feet, and a minimum of 40,000 square feet, based on targets of 100 to 500 employees per meter, and an estimate of average square footage per employee. According to the International Facilities Management Association's (IFMA), research on 1,422 offices in the United States, the office space per employee has varied between 392 to 435 square feet per employee from 2007 to 2009.[27] Since they attribute much of the increase in square footage to corporate layoffs, I use an average value of 400 square feet per employee. The range of 40,000 to 200,000 square feet then corresponds to an electric meter covering between 100 and 500 employees at one time. At 100 employees or fewer, the effects of metering should be meaningful, as each person has an average of a 1% or greater

[27] "IFMA workplace study: Average space per employee up 40 sf since 2007, likely due to corporate layoffs," Building Design & Construction, June 9, 2009, http://www.bdcnetwork.com/article/380638-IFMA_workplace_study_Average_space_per_employee_up_40_sf_since_2007_likely_due_to_corporate_layoffs.php

effect on the total energy use, but as the size of the group grows, the relative effectiveness of the meter should decrease. At 500 employees per meter, I estimate that the effect of the meter is zero.

Therefore, any building with a metered area of less than 40,000 square feet does not have its savings potential reduced, and any building with a metered area of greater than 200,000 square feet receives zero potential savings from the installation of an electric meter. Fortunately, the largest metered area of any building is 143,000 square feet, and in this case, the estimated savings potential is reduced by 64% to account for its large metered area.

As an added benefit, some of the buildings are wired in a way that the feeds to the building not only divide the building by geography, but also separate out the "central plant" from the rest of the building. Since the central plant typically contains HVAC equipment and air compressors, it conveniently separates that load from lighting and plug loads. This benefit is not incorporated into the calculation, although it would be possible with an analysis of the one-line diagram for each of the buildings in the list.

7.2.2 Statistical Analysis of Reduction Potential

Statistical analysis of energy data can provide valuable clues on how energy is used in a building, without the need for a detailed energy audit of what activities go on inside. In addition, statistical analyses can be completed by a computer on a real-time basis to monitor for patterns that suggest inefficient energy use or abnormal usage patterns.

When considering where to locate electric meters, statistical analysis is used to determine which buildings offer the greatest potential for energy savings. Put another way, this analysis can show which buildings are presently using electricity in an inefficient manner.

7.2.2.1 Energy Intensity

One way to estimate energy use efficiency is to look at the average energy consumption (over a week or month period) and normalize it to area (square footage) or population, to give a value called "energy intensity," which allows the comparison of buildings with others or with a baseline value. Buildings that have higher energy use per square foot or per person would be considered to be less efficient in their use of energy, and therefore have a greater potential for energy savings.

Energy intensity can be calculated with weekly or monthly data, with the primary difference being that feedback only occurs as frequently as the data (i.e. monthly data yields monthly feedback). More frequent sampling would allow for weekend and weekday energy intensities or even daytime and nighttime energy intensities. Although RMS is only able to collect real-time data from a few buildings now, they have been reading analog meters by hand to calculate weekly consumption data for 25 buildings since April 2009. Figure 16 shows the energy intensity normalized by area for each of the buildings from weekly readings for the week of May 31 to June 6, 2009, while Figure 17 shows the same consumption normalized by headcount (population) for each building during the same time period. In Figure 17, buildings with populations fewer than 10 people were removed as these buildings are generally very industrial and much of the energy supports a process rather than supporting individual employees.

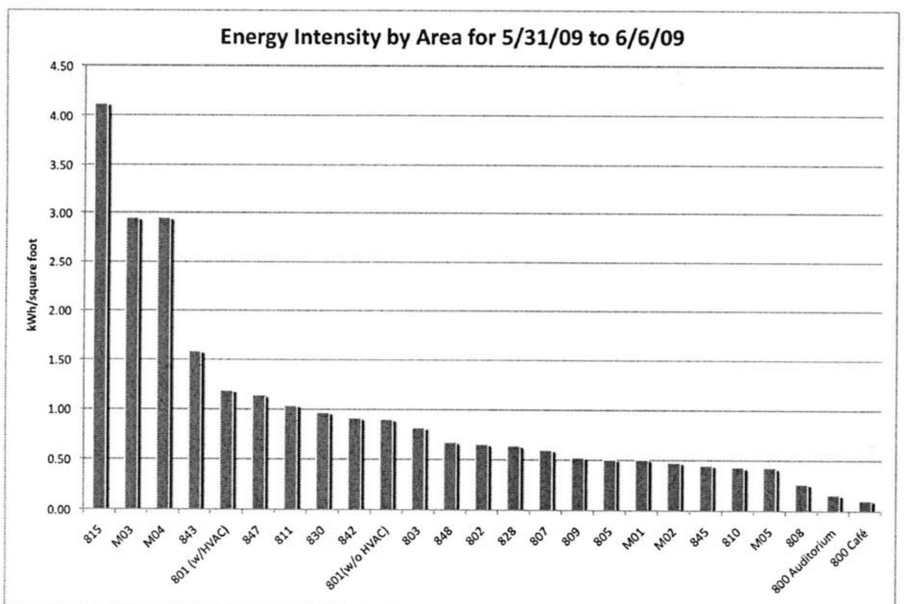

Figure 16: Energy intensity by area for buildings at RMS Airport Site

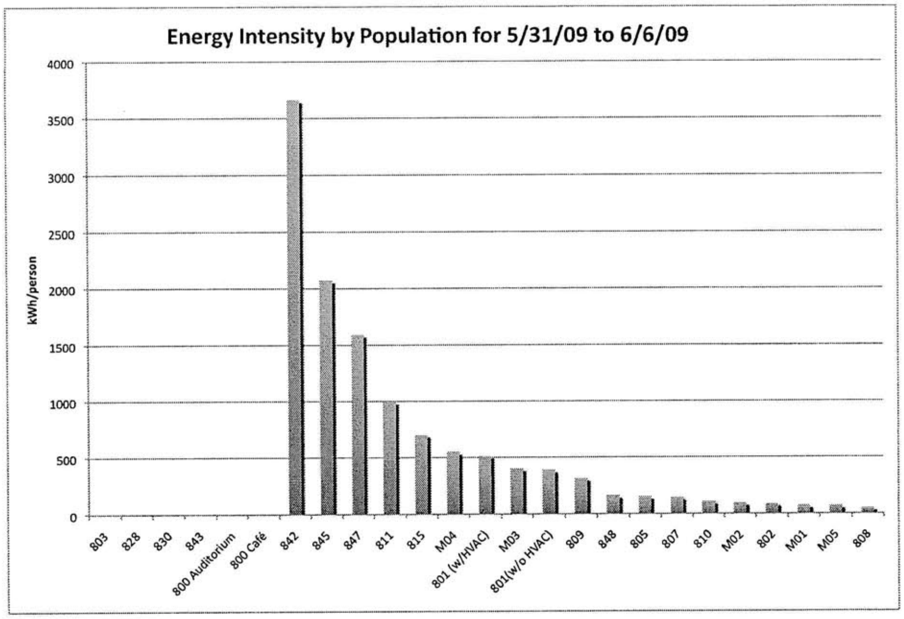

Figure 17: Energy intensity by population for buildings at RMS Airport Site

Clearly, there is a wide range of energy intensities by square footage and by population. Buildings that are primarily office space (such as M05, where I worked) have a much lower energy intensity than buildings that are used as laboratories or factories. This data set also does not differentiate between energy consumption of the building and energy consumption to heat and cool the building (HVAC). For most buildings, the HVAC load is combined with the total building consumption, but it was not explicitly stated with this metering data. The effect of HVAC on energy consumption is significant, particularly in Tucson during the summer. As an example, Building 801 has a portion of its HVAC usage metered separately, and that HVAC makes up 17% of the total usage (0.90 and 1.19 kWh/sqft/week.) However, the 17% is only a portion of its HVAC consumption because Building 801 receives chilled water from a chilled water loop that feeds a number of buildings on the Airport Site. The 17% portion primarily goes to the fans required to circulate air throughout the building as it is being heated or cooled.

Energy intensities by population generally differentiated buildings by use. The lower energy intensity buildings (by population) were typically office space, while the middle range are mixed between office and laboratory or manufacturing, and the highest ones are primarily labs and manufacturing space that have few (non-hourly) employees. Therefore, this type of analysis is only useful for comparing buildings of similar use to determine if electricity is being used efficiently or not.

7.2.2.2 Consumption Variation Overview

A second way to measure efficiency is to examine the variation in a building's energy use. At the most basic level, the goal of this analysis is to determine whether the building is using different amounts of power at different times. Buildings that use energy efficiently are turning devices on and off as they are needed, particularly at night, when the building is unoccupied, rather than leaving them on all the time. Statistical analysis is a rapid method of determining the outliers in the system without requiring the time to learn the details about each building. For office space in particular, which is typically occupied only ten to twelve hours per day, the energy saving potential from turning items off during the unoccupied periods is equivalent to replacing these appliances with ones that use half as much energy.

Figure 18, below, shows a graph of electricity demand for two buildings at the Airport Site over the month of June 2009. Building 809, in blue, shows a range in demand from 130kW to 170kW, while building 814 South shows a range from 15kW to 170kW. While both buildings reach roughly the same peak demand over the course of the month, Building 814 South has significantly lower usage during nights and weekends than Building 809 and shows greater variation throughout the day. As a first pass, Building 814 South is using electricity much more efficiently than Building 809.

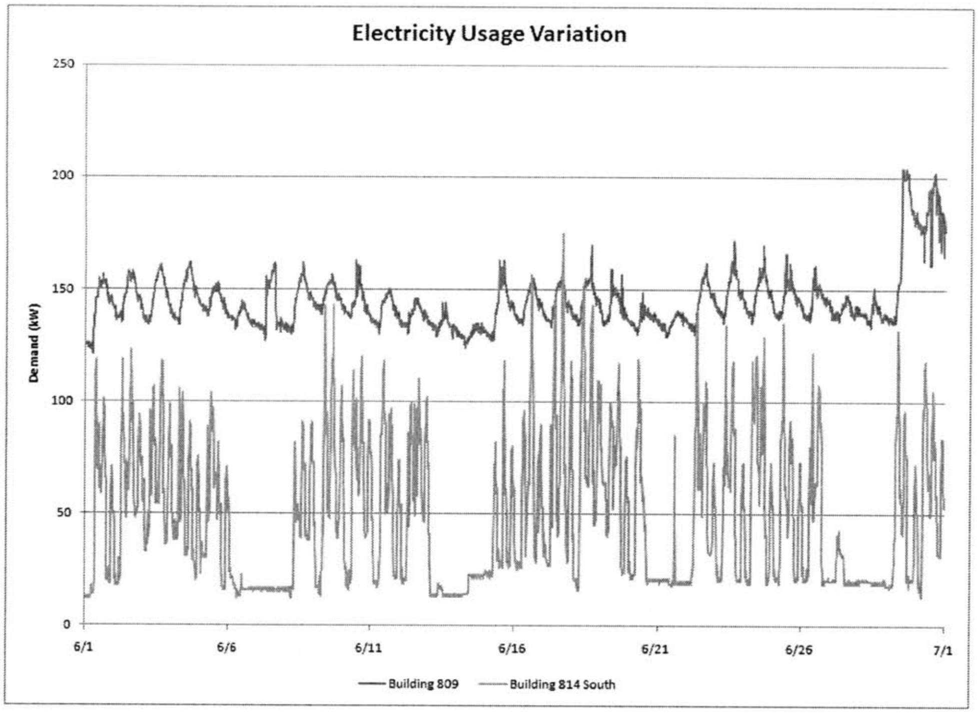

Figure 18: Comparison of high and low variation buildings at the RMS Airport Site

Additional research into Building 809 reveals that it is a clean room and must maintain certain environmental parameters 24/7 or risk going out of specification. While this explains why the building has very constant energy use, it also suggests great opportunity to conserve energy, particularly on weekends when people are not present (and not creating dust particles).

Building 809 shows that buildings that are operated three shifts per day, or need to maintain certain parameters 24/7, will show up as poor performers. Nonetheless, these types of buildings are also the largest energy users and would have the most to save from efficiency improvements.

An advantage of analyzing usage variation instead of energy intensity is that variation is less sensitive to the types of loads measured in each system. For example, if a building is designed with a central plant that provides HVAC, which is metered separately from the building, it will show a lower energy intensity than one with one meter that covers the building and the central plant, even though the overall energy intensities are the same. However, using variation analysis, if both buildings are turning off energy consuming devices (including lights, computers, and HVAC) when the building is unoccupied, both should show similar variation (by percentage) despite the metering and wiring differences.

Since this variation analysis looks for changes in usage from day to night and weekday to weekend, the current data set of weekly or monthly energy data does not have sufficient granularity to be analyzed. This statistical analysis of electricity usage reduction potential can only be achieved with highly granular data from digital electric meters. At the Raytheon Airport Site, the existing metering infrastructure allowed the analysis of only some individual buildings and some groups of buildings as well. Unfortunately, it could not be completed for every building on the site, although that is part of the motivation for additional electricity meters.

Using the one-line diagram for the electrical distribution for the Raytheon Airport Site, I was able to determine which buildings and which circuits are metered by the 50 meters installed in the electrical substation. Since the meters were installed for maintenance and power quality monitoring, they do not necessarily provide the granularity that an energy manager would desire. Of the 50 meters installed in the substation, 18 monitor tie-breakers (links between different circuits for maintenance), one circuit is unlabeled, and only the remaining 31 meters can be used to analyze variation in usage patterns.

7.2.2.3 Electricity Demand Min, Max, and Average Ratios

Taking 15-minute demand data from June 2009, I was able to calculate the minimum, maximum, average, and standard deviation of electricity demand for each of the 31 circuits. While these statistics give a picture of how energy is being used in each circuit, they are not normalized to the size of the building. Therefore, it is important to divide each statistic by the average power consumption. To determine the level of variation, I first compared the minimum, average, and maximum demands. Although the building with the best energy performance would be the one with the greatest range between maximum and minimum 15-minute demands, the maximum and minimum are subject to outliers. For example, a power outage during the sample period would cause a demand reading of zero, even if everything in the building were usually left on. Similarly, the maximum value could have an outlier for a single day when power usage was abnormally high, which would show that the building is more efficient than it truly is. Using the average power consumption for the time period smoothes out the outliers. In addition, if someone were trying to "improve" their efficiency score by altering the minimum, maximum, or average values, the average would be the most difficult to change.

Table 3, below, compares different ratios using minimum, average, and maximum demand readings in an attempt to develop a metric that rewards low energy use and allows the comparison of different sized buildings.

Ratio	Advantages	Disadvantages
Minimum/Average	Rewards the absolute minimum demand. The average value is relatively unaffected by spikes in max demand.	Outlier in the minimum value can skew the results.
Minimum/Maximum	Shows the full range of electricity demands and penalizes high maximum demand.	Outliers in the minimum and maximum can give an inaccurate picture of the whole time period. Using maximum value tends to "reward" a high maximum value.
Average/Maximum	Penalizes high maximum demand spikes.	Using maximum value tends to "reward" a high maximum value and without using minimum value, there is no reward for reducing the minimum value.

Table 3: Comparison of electricity demand ratios

In general, lower values for each of these ratios is intended to show greater efficiency, and higher values show lower efficiency. Since the purpose of these ratios is to encourage the turning off of devices, particularly at night, the ratio must contain the minimum demand value. This not only rewards buildings that turn off devices at night, but also provides a clear way of improving the metric. The maximum demand value, on the other hand, improves the ratio only when it increases, which promotes the wrong behavior. In order to normalize the minimum value, the best option is to use the average power consumption, as that gives the best overall picture of the building's energy use. For any building that had a minimum demand value of "0" during the measurement period, that reading was assumed to be an outlier, and the next lowest demand value was used as the minimum value.

Figure 19, below shows the range of minimum over average demand ratios for digitally metered buildings in June 2009.

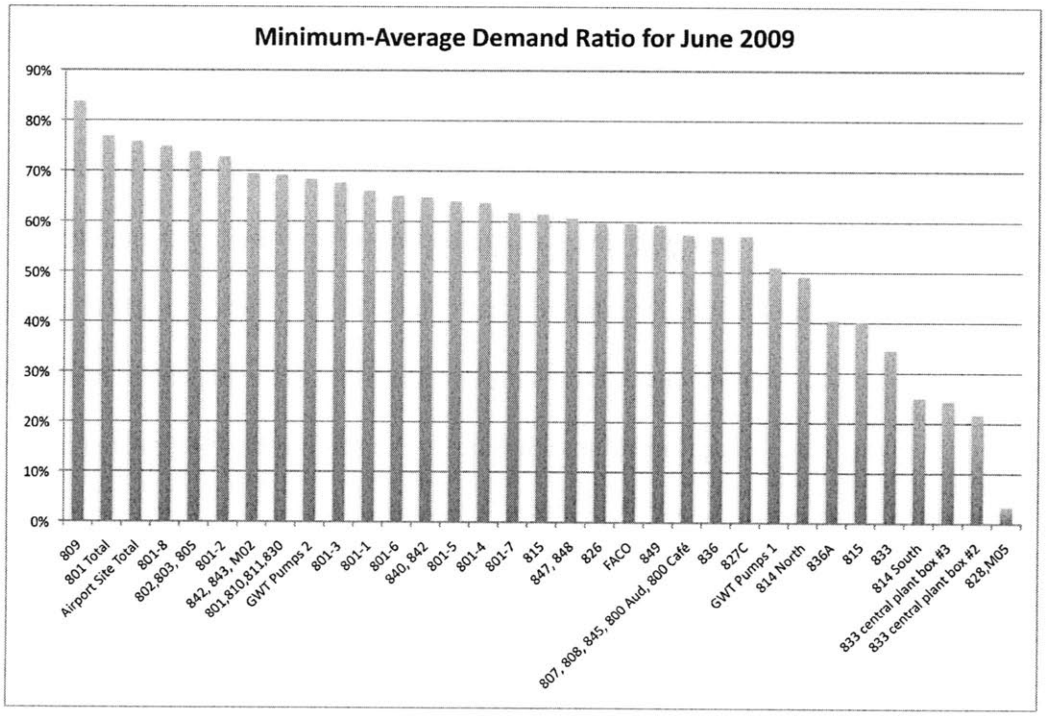

Figure 19: Ratio of Minimum Demand to Average Demand for 12 Buildings in June 2009

Clearly, there is a wide range of ratios, from 3% to 84%, suggesting that some buildings vary their power use more than others. The implication is that greater variation means better control of the power consuming devices and therefore a more efficient use of energy.

Also, the presently installed digital meters only allow the differentiation of 12 individual buildings. The graph shows the groups of buildings that can be differentiated, but it is not clear which buildings within those groups are using energy more efficiently. In addition, as circuits get more aggregated, the usage pattern tends to "flatten" with less variation in the demand. In Figure 19, the 801 Total has a much higher Min/Avg ratio than any of the individual 801 meters alone (801-1 through 801-8). However, Building 801 Total and Building 809 show less variation than the whole airport site, which suggests that they both have extremely low variation in their consumption. (Building 809 also was a standout for low variation when its usage was graphed over a monthly time period in Section 7.2.2.2)

7.2.2.4 Standard Deviation and Composite Variation Ranking

Another method of analyzing variation in electricity consumption is to look at the standard deviation of electricity demands. Standard deviation is a measure of how much the data points are spread out from the average value, which gives a good picture of how energy demands have varied throughout the measurement period. Standard deviation also offers a better method of filtering out outliers in minimum and maximum values than simply removing zero values from minimums or trying to remove spikes from maximum values. Similar to the minimum, average, maximum analysis, the preferred method of normalizing the readings across buildings is to use the average demand for the whole time period.

Figure 20, below, uses the same 15-minute data from June 2009 and ranks the buildings from the highest to lowest in the ratio of standard deviation to average electricity demand. For this metric, higher values are more desirable, as they show greater variation in usage throughout the month.

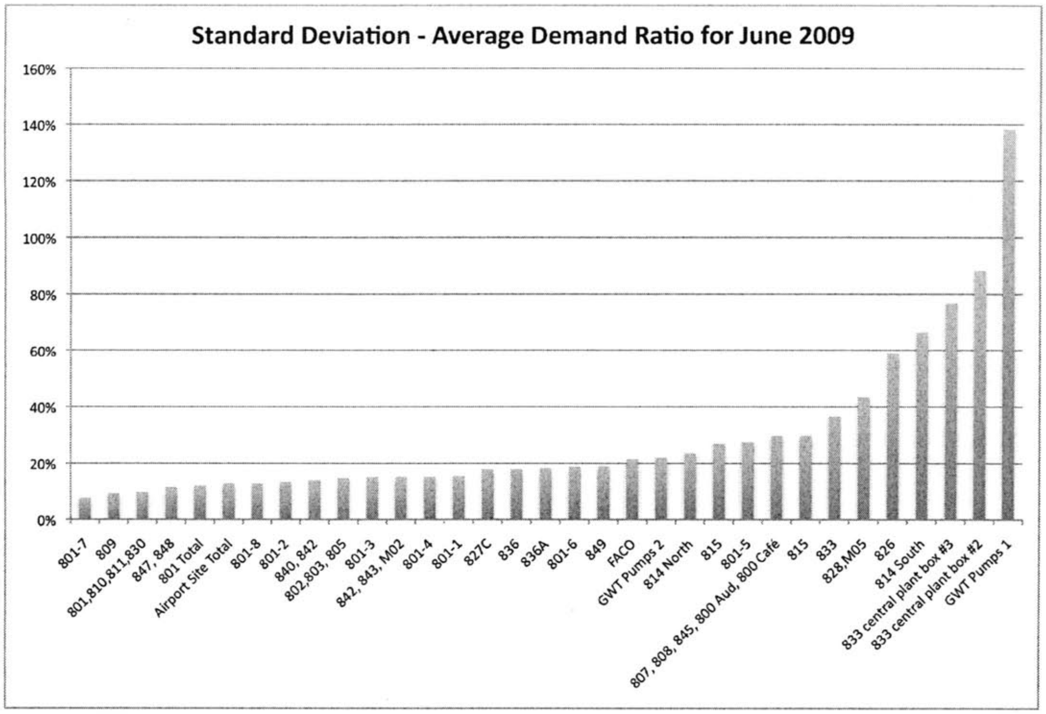

Figure 20: Ratio of Standard Deviation to Average Demand for 12 Buildings in June 2009

Similar to the minimum demand to average ratio, there is a wide range of results for various buildings. Since the standard deviation of a set of data can be greater than the average of the set, the ratio has the potential to be greater than 100%. From this graph, it is clear that some buildings are clearly using different amounts of energy at different times, while others have a very constant demand.

Comparing these results with the usage graph in Section 7.2.2.2, Building 809 has one of the very lowest standard deviation over average ratios, whereas Building 814 South has one of the highest ratios, as expected. Also, the 801 Building total has a lower ratio, indicating less variation, than all but one of the sub circuits that make up that total. Building 828 and M05, which had a very low (and favorable) ratio for minimum over average, also showed good performance in the standard deviation to average ratio.

The top performers for both ratios were the Building 833 central plants and the "GWT Pumps". These two buildings house industrial equipment that is used for heating and cooling, and groundwater treatment, respectively. Since these devices are very significant energy consumers and are controlled by an operations center, they show very large swings in their energy consumption. While they are both very large energy consumers, and could likely benefit from efficiency improvements in the devices, the variation in their usage shows that the current devices are being turned on and off, hopefully according to their need.

As both the minimum over average ratio and the standard deviation over average ratios are valuable measures of a building's usage pattern, they were incorporated into a composite score to be used in the ranking of buildings for energy savings potential in Section 7.5. The goal of the composite score was to be higher for higher performing buildings, and to combine both Min/Avg and StdDev/Avg values. Since high performing buildings will have lower Min/Avg values, and since StdDev/Avg values vary from 0 to greater than 1, the composite score is calculated as a sum of StdDev/Avg and (1-Min/Avg). This results in a range of values from 25% to 187%. See Figure 21 below to summarize the results.

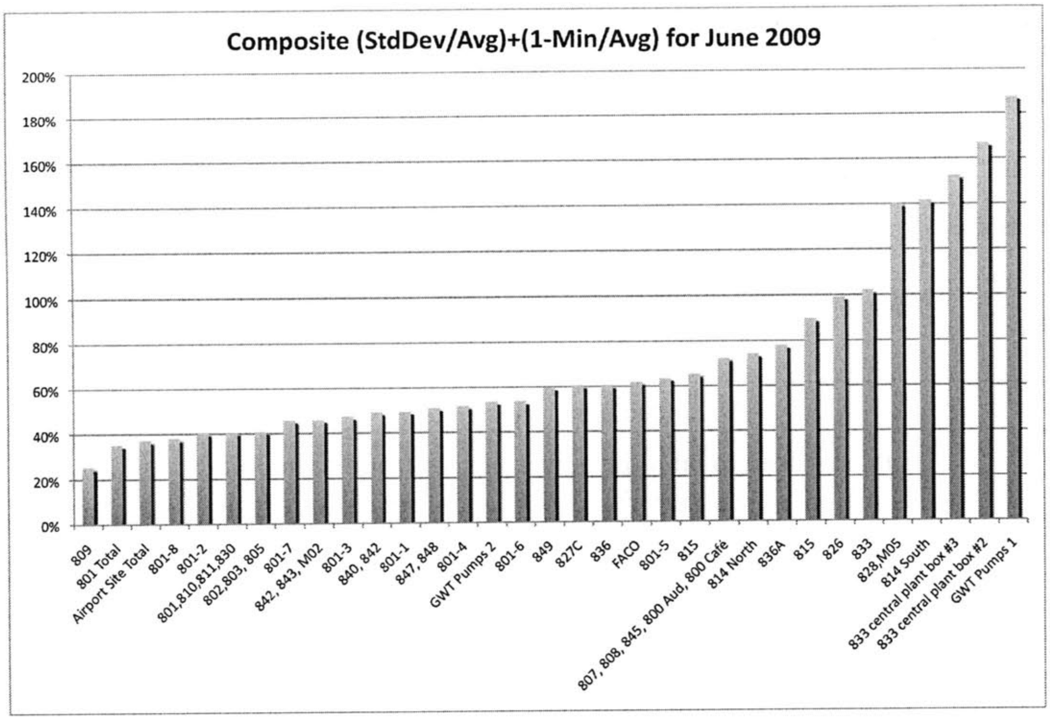

Figure 21: Composite usage patterns for 12 Buildings in June 2009

7.3 Hardware and Installation Costs

Collecting detailed electricity usage data requires digital electric meters to measure the flow of energy, network interface cards to transmit the meter readings over a network, and a data collection server to save the readings as they are created. While the data collection server (and associated software) are a one-time cost, to collect data for each additional circuit requires an additional electric meter and network interface card. When evaluating the cost of adding additional meters, only the incremental cost of the electric meter, network card, and installation were considered.

Raytheon uses SquareD PowerLogic brand meters because of their reputation for high quality, and their compatibility with the existing hardware, both in Tucson and across the Raytheon business units.

Table 4, below, lists the electric meter hardware items and the suggested retail prices from the manufacturer catalog.

Part Number	Description	Suggested Retail Price[28]
PM210	Basic electricity meter. Primarily measures power (kW) and energy (kWh)	$1000[29]
PM800	Advanced electricity meter. Primarily used to monitor power quality (total harmonic distortion, power factor). Also is capable of data storage onboard.	$2390
PM8ECC	Network interface card. Connects up to 32 meters to a LAN connection allowing real-time, remote data collection.	$1150

Table 4: SquareD PowerLogic electric meters with descriptions and suggested retail prices

For energy monitoring purposes, the very basic PM210 meter is more than sufficient. A PM820 meter is useful to maintenance technicians who monitor power quality and need to diagnose power problems. Typically, this type of meter is only used on main feeds to a building, because of its higher price.

Installation cost for these electric meters is roughly $1,000 per meter, based on a number of quotes from local electrical contractors in Tucson. This cost includes the installation of the meter and associated current transformers that are placed around the load wires, installation of metal conduit to provide a network drop for the meter, and pulling of network cable between the nearest data closet and the network interface card for the meter.

[28] Schneider Electric Catalog, 2009

[29] Author's estimate, from contractor quotes, since the PM210 is only sold in prefabricated enclosures.

In total, the estimated actual cost for installing a PM800 meter with PM8ECC card is $4,000 (after applying typical wholesale discount rates). For some of the meters on the Tucson site that are already digital meters but only require the communication portion, the estimated additional cost is $2,000, which includes the network card and associated installation.

Organizationally, allocating funds to a special project to retrofit buildings and install electric meters is much more challenging than incorporating meters into remodeling projects or new construction. With new construction, the incremental cost of additional meters is generally small compared to the overall project cost, while creating a special project for electric meters puts electric meters in direct competition with many other projects each year. Unfortunately, waiting for every building to be remodeled before upgrading metering would take ten to twenty years, so the best course of action is to begin including meters in projects, in conjunction with a few dedicated electric metering projects.

7.4 Savings Potential

7.4.1 Energy conservation estimates

Estimating the savings potential from installing electric meters presents a number of challenges. First, although meters certainly have the potential to reduce electricity use, the actual behavior change does not occur simply because the meter is installed. Savings occurs after the data collected by the meters is converted to useful information and fed back to users. Meters are the first step in this process, but the fraction of the savings that should be assigned to the meters themselves is unclear. Second, much of the literature on energy savings through information feedback has focused on the residential market. This area is easier to study because most homes already have a dedicated electric meter, and the user of the electricity pays the electric bill. In a business setting, there is not the same alignment between users and payers, which probably results in a weaker effect from information feedback.

The literature on residential energy feedback mechanisms has a range of findings, from a 5-15% reduction in use (Darby, 2006), to a 0-18% reduction in use (EPRI, 2009). One of the goals of this thesis is to show that meters can be an economical (and positive NPV) investment, even with very low projected levels of energy savings. Therefore, the range of energy savings potential for the following calculations was completed for a range of 0 to 3% as a result of installing electric meters. Ideally, facilities managers armed with energy usage data can deliver 15% reductions in energy use, but for this thesis, we will only attribute up to 3% to the installation of the electricity meter. As a reference point, Raytheon Corporation reduced their energy consumption (normalized to revenue and corrected for inflation) by 31% from 2002 to 2008, (6% per year) as a result of dedicated energy management.[30]

7.4.2 Benefits of digital metering beyond energy conservation

In addition to the energy savings benefits from collecting detailed data from digital electric meters, there are other benefits that improve processes or reduce costs in other areas, but are difficult to quantify:

1) *Reduced time lag in receiving feedback.* Since the data collection interval is equal to lag time, the more frequently data is collected, the faster the feedback. Utility bills come every month, and individuals can be persuaded to read meters manually on a weekly or daily basis, but only digital meters can provide real time feedback on energy consumption. When making changes to the system, this gives immediate feedback on whether the change is good or bad. Although faster feedback does not necessarily save more energy, it speeds up the process significantly.

2) *Significantly greater granularity.* In addition to reducing time lag, digital meters also provide much greater granularity. Since trends in data can only be observed over multiple data points, monthly data can only show trends over many months, weekly data, over many weeks, and 15-minute data, over the course of a few hours. Digital meters are critical to begin to understand the usage patterns between night and day and weekday and weekends. As many buildings use as much as 70% of their peak power during the "off" hours, understanding when the power is being used is very important to reducing power usage.

[30] "Raytheon Corporate Responsibility Report 2008," *Raytheon Corporation,* p17.

3) *Collect the same information as the electric utility.* The "Large Light and Power" rate structure that covers the Airport Site has both demand and energy prices. The local utility is monitoring the average demand over 15-minute periods and the top three periods of the month are averaged and billed at a rate of $19.02/kW. At the least, digital meters allow verification that the utility's meter is accurate. With a small investment in the building automation system, large power consuming devices, such as air conditioning chillers, can be synchronized with the electric meter to attempt to minimize consumption during the highest demand periods of the day.

4) *Reduce busy work for employees.* A digital metering system automatically reads the meters every 15 minutes (or more frequently) and stores the data on a central server. This eliminates the time required for employees to walk or drive around to read meters that are often in dark and dusty electrical closets. Using an estimate of 4 minutes of time to read a meter and enter the data into a spreadsheet and estimating that this employee's time is valued at $50/hr, reading each meter once per week costs $173/meter/year. See Equation 1, below, for details. On an individual basis, $173 is not significant, but at a site the size of the Airport Site, there could easily be 100 to 200 meters to read, making meter reading a $20,000+/year cost.

$$\frac{4\,\text{min}}{meter}\times\frac{hr}{60\,\text{min}}\times\frac{\$50}{hr}\times\frac{52wks}{yr}=\frac{\$173}{meter\cdot yr}$$

Equation 1: Calculation of labor cost for weekly meter reading

7.5 Results from ranking buildings at RMS Tucson

The underlying principle when ranking buildings as potential locations for energy meters is a simple comparison between the cost of installing the meter and the potential energy savings. While the cost is generally easy to calculate, the potential savings is a combination of a number of factors regarding the parameters of the building, its usage history, and its electric rate structure.

7.5.1.5 Energy Savings Estimate

The energy savings estimate combines the factors of historical energy usage pattern and the metered square footage to scale the savings potential, multiplies that value by the average energy use for a building of its size and the cost of electricity for that building, and finally adds the avoided cost of $173 per meter of employee time. Equation 2, below, summarizes the savings estimate, with greater detail of the methodology in the following paragraphs.

$$\$Savings/Year = \left[1.5\% + (1.5\% \times CompositeScorePercentile)\right] \times \begin{bmatrix} SqFt > Max, 0 \\ 1 - \left(\dfrac{SqFt - Min}{Max - Min}\right) \\ SqFt < Min, 1 \end{bmatrix} \times SqFt \times \left(AvgkWh/SqFt/Year\right) \times \left(\$/kWh\right) + (\$173 \times numberofmeters)$$

Equation 2: Yearly energy savings estimate

As discussed in Section 7.4.1, the savings range for buildings at RMS was determined to be 0 to 3% based on current literature on the effectiveness of metering and information feedback to users.

This savings rate was then adjusted to take into account the data available on energy usage patterns. Only 26 buildings (of the 153 considered) could be analyzed, given the level of meters currently installed. The analysis from Section 7.2.2.4 provides a composite score, which is a combination the ratios of Min/Avg and StdDev/Avg. To use this composite score for modifying savings potential, the savings potential was scaled from a maximum of 3% savings to 1.5% savings (50% potential reduction), by the relative composite score within the range. Buildings without savings data were given a middle savings value of 2.25%.

The formula also scaled by metered area, with upper and lower bounds on the effective metered area. For buildings at the upper bound of metered area, the factor is 0, resulting in no energy savings, and at or below the lower bound, the factor is 1, gaining the full effects of the electricity metering. Between the upper and lower bounds is a linear scale, reducing the savings potential of the electric meter by the appropriate amount.

To convert these savings percentages into financial savings requires an estimation of each building's usage. Without meters on the buildings, there is no way to know the actual present usage. To estimate, I used data from the Energy Information Administration (EIA), a branch of the US Department of Energy (DOE). As of 1995 data, the EIA estimates an average of 97,200 Btu per square foot of office space. (28.5kWh/sqft)[31] Multiplying the total square footage by the average energy consumption per square foot gives an estimate of the total energy use of a building per year.

Bringing all of these scaling factors into account yields Equation 2, which was used to determine the potential savings per year for each building. Table 5, below, summarizes the assumptions used in the calculations.

Parameters	**Value**	**Units**
Cost to install meter (per meter)	$4,000	
Cost of Capital	12%	
Sq ft/meter where it is ineffective	200,000	Sq ft/meter
Sq ft/meter where it reaches theoretical effectiveness	40,000	Sq ft/meter
Energy Reduction Percentage Estimate		
Highest variation in usage (lowest savings potential)	1.50%	
Lowest variation in usage (highest savings potential)	3.00%	
No data on usage pattern	2.25%	
Average Yearly Energy Consumption per sq ft		
	28.5	kWh/sqft/yr
Average Cost/kWh	Price $/kWh	Units
AIRPORT	$0.070	$/kWh (blended)
BIKE SHOP	$0.110	$/kWh (energy)
CSC	$0.110	$/kWh (energy)
REYWEST	$0.110	$/kWh (energy)
RITA ROAD	$0.068	$/kWh (blended)

Table 5: Parameters for electric meter location rankings

7.5.2 Financial Results

Finally, with data for the cost of electric meter upgrades, and the estimated total energy savings potential, it was possible to calculate the return on investment (simple payback period) and the net present value (NPV) of the investment.

Ranking the 153 buildings examined for RMS yielded five buildings with a simple payback of under one year, 19 buildings with a positive NPV over two years, and 48 buildings with a positive NPV over 10 years.

See Table 6, below, for complete data for the 19 buildings that show a positive NPV over two years for electric meter installations.

[31] "A look at office buildings - How do they use energy and how much does it cost?" *Energy Information Administration,* September 11, 2000, http://www.eia.doe.gov/emeu/consumptionbriefs/cbecs/pbawebsite/office/office_howuseenergy.htm

BLDG	SITE	TYPE	TOTAL GROSS SQ.FT.	Submeters Required	Avg Sq Ft Metered With Submeters	Estimated Cost	Net Savings Percentage	Estimated Yearly Energy Savings	ROI (years)	NPV (2 year)	NPV (5 year)	NPV (10 year)	Notes
M09	REYWEST	OFFICE	143,630	1	143,630	$2,000	0.79%	$3,742	0.5	$4,539	$11,705	$19,360	Communication upgrade only.
848	AIRPORT	OFFICE	244,370	3	81,457	$6,000	2.05%	$10,501	0.6	$12,390	$32,497	$53,977	Communication upgrade only.
845	AIRPORT	LAB	64,393	1	64,393	$2,000	2.18%	$2,967	0.7	$3,229	$8,911	$14,980	Communication upgrade only.
802	AIRPORT	OFFICE	51,907	1	51,907	$2,000	2.64%	$2,910	0.7	$3,132	$8,705	$14,657	Communication upgrade only.
M10	REYWEST	OFFICE	72,000	1	72,000	$4,000	1.80%	$4,236	0.9	$3,588	$11,698	$20,363	
M11	REYWEST	OFFICE	58,165	1	58,165	$4,000	1.99%	$3,810	1.0	$2,868	$10,163	$17,956	
M12	REYWEST	OFFICE	58,165	1	58,165	$4,000	1.99%	$3,810	1.0	$2,868	$10,163	$17,956	
807	AIRPORT	OFFICE	167,127	2	83,564	$8,000	1.87%	$6,573	1.2	$3,966	$16,552	$29,997	
805	AIRPORT	OFFICE	225,164	4	56,291	$16,000	2.56%	$12,214	1.3	$6,356	$29,742	$54,724	
M02	AIRPORT	OFFICE	92,773	1	92,773	$4,000	1.51%	$2,964	1.3	$1,436	$7,112	$13,175	
M24	RITA ROAD	OFFICE	120,691	1	120,691	$4,000	1.12%	$2,782	1.4	$1,130	$6,456	$12,145	
M22	RITA ROAD	OFFICE	218,956	3	72,985	$12,000	1.79%	$8,098	1.5	$2,972	$18,478	$35,043	
843	AIRPORT	LAB	45,280	1	45,280	$4,000	2.72%	$2,627	1.5	$869	$5,900	$11,274	
849	AIRPORT	LAB	46,892	1	46,892	$4,000	2.57%	$2,574	1.6	$780	$5,709	$10,975	
M24 IBM	RITA ROAD	OFFICE	54,841	1	54,841	$4,000	2.04%	$2,343	1.7	$388	$4,873	$9,664	
814	AIRPORT	OFFICE	43,015	1	43,015	$4,000	2.50%	$2,317	1.7	$345	$4,783	$9,523	
M20	RITA ROAD	OFFICE	198,954	4	49,739	$16,000	2.11%	$8,839	1.8	$653	$17,578	$35,659	
801	AIRPORT	OFFICE	592,734	17	34,867	$68,000	2.91%	$37,340	1.8	$2,392	$73,887	$150,263	
715	REYWEST	OFFICE	27,948	1	27,948	$4,000	2.25%	$2,144	1.9	$53	$4,159	$8,545	

Table 6: Two-year positive NPV electric meter installation locations

7.5.2.6 Discussion

Looking at the results, there are a few parameters that consistently explain why some buildings are better investments than others. First, the top four buildings in Table 6 have half of the installation cost, per meter, than the other buildings because they already have digital meters installed. These four buildings only need a communications upgrade in order to collect, store, and analyze the usage data. This reduces the payback period significantly and improves the NPV as well. Secondly, many of the top buildings are at the ReyWest site, primarily because electricity costs 57% more at the ReyWest site than at the Airport Site or Rita Road. The "Net Savings Percentage" shows the estimated net savings percentage after scaling for both metered square footage and for electricity use pattern. Interestingly, building M09 has a very large metered area, and an unknown usage pattern, resulting in a very low net savings percentage of 0.79%, yet has the shortest simple payback of any building at RMS because of the low cost to upgrade and the high cost of electricity. NPV looks at a longer term than simple payback, and the larger Building 848 quickly exceeds M09's NPV over two years, and Building 801, the largest at RMS Tucson, shows the greatest potential with an NPV of $150,263 over 10 years.

In conclusion, although this analysis used very conservative estimates for energy savings potential (0 to 3%), and then scaled them down further to account for metered area and usage patterns, there are still a large number of buildings that show a short payback period, and very promising net present values.

8 Chapter 8: Conclusions

8.1 Desired future state

8.1.1 Examples of energy usage feedback

The installation of electricity meters at RMS is a very positive first step towards energy conservation through feedback and behavior change. However, to move from the 0-3% savings estimate from the meters alone to the 5-25% savings potential through feedback requires stronger feedback mechanisms. One of the issues with many current energy monitoring systems is that they are developed for facilities managers, not end users. In many situations, it is the end users who need to change their behavior, and they are the ones with the least understanding of energy and how it is being consumed. Professor Sarma's research on electricity use feedback with associated website is an excellent example of a clear graphical display that is simple and easy to understand. Another example that is particularly intuitive is Arizona State University's "Campus Metabolism" website, which gives complete energy consumption information in electricity, heating, and cooling, and even includes renewable generation. See Figure 22, below, for a screenshot of the website.

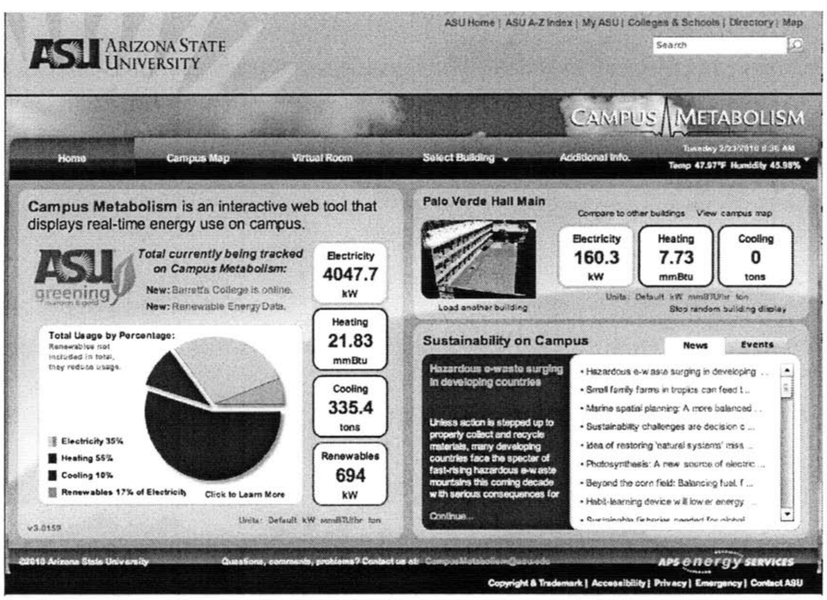

Figure 22: Screenshot from ASU's Campus Metabolism Website

Ideally, RMS would be able to take the data that they are collecting through the installed electricity meters and output it into a website like this one. Each building could have a profile, and comparisons could be drawn between different buildings at the RMS site, between Raytheon business units, and even individual buildings in different Raytheon business units.

8.1.2 Broadening the measurement and feedback horizon

Since electricity is the largest source of energy at RMS, is the obvious first choice for measurement and control. However, to get a better picture of how energy is consumed at RMS, the metering network would be expanded to include natural gas, chilled water, and process steam. While every building uses electricity for lighting and plug loads, not every building uses electricity or natural gas within its walls for heating and cooling. Chilled water and steam are sometimes produced in large central plants and then shared among a number of buildings, making it difficult to account for the consumption of any individual building. The goal of separately metering each type of energy consumption is to get a more accurate picture of how the building as a whole uses energy. With the complete picture, it is easier to compare the building to other similar buildings, and it is easy to see which buildings may be using energy inefficiently. For example, a building could have very efficient lighting and have very low electricity consumption, but have insufficient insulation and be putting a significant load on the chilled water system. Measurement of all energy flows in and out of the building would give a better and fairer view of how building use energy.

8.2 Additional energy conservation opportunities

8.2.1 Peak Shaving and Demand Response Potential

Since RMS is such a large customer of electricity, it is billed by total electricity consumption (energy) and maximum electricity demand (power). This results in very inexpensive energy during the night and potentially very expensive energy during the peak and offers the opportunity to reduce the consumption of the most expensive energy. Also, since energy consumption at peak times tends to cause utility companies to operate their most polluting, inefficient power plants, reducing demand at the peak not only saves money, but can have positive effects on the environment as well.

Fortunately, RMS has an advanced building automation system that can be used to reduce peak demand. Although this thesis does not focus on strategies for demand response at the enterprise level, as more electric meters are installed and the electricity usage pattern is better understood, the potential to track that pattern and reduce peak demand seems significant.

8.2.2 Organizational structure

Lastly, the availability of energy data opens the doors to incorporate this data into operational metrics. Raytheon has been known in the past for skillful use of metrics in manufacturing and operations, and energy could be included in those metrics as well. The challenge in this area is to ensure that the methodology of data collection and analysis is completely transparent to those who are affected by the data. This thesis does not go into detail on the specific management structure required to take advantage of this data, but suggests that this data could provide value in addition to good energy information and behavior change through feedback.

8.3 Lessons Learned

1) **"Base Load" offers significant potential for energy savings.** RMS has a constant base load that is 61% of peak load. Intuitively, it seems like a significant amount of power for periods when most employees are not there. However, without detailed energy meters, it is very difficult to pinpoint where this energy is being used. Without that information, it is not possible to determine what can be done to minimize that consumption.

2) **People respond quickly to feedback.** Although I manually collected data from meters that were already available and provided only 12 hour granularity, the experiment in building 808 was able to achieve tangible changes in energy use in only one month.

3) **Hardware cost is a significant barrier to meter deployment.** Meters have limited deployment now because of their cost, and as meters become more granular, the cost of the meter outweighs the cost of the energy that will ever flow through the meter. Professor Sarma is on the right path with his goal of developing inexpensive networks of energy meters.

4) **Efficiency improvements are best installed as a part of a renovation or new construction.** First, the incremental cost of an electric meter (or upgrading a proposed electric meter to be able to collect data) to a new project is a much less lower than replacing an already existing meter. Second, electric meters are a trivial fraction of the cost of a large renovation or new building, but when bundled into their own project, appear to be a significant cost.

5) **Facilities engineers are not opposed to installing meters, but they generally are not familiar with the technology.** Since feedback of energy data is not common in commercial settings, most facility engineers are unfamiliar with energy meters available on the market, or which ones interface with the existing data collection infrastructure. I found that after promoting meter installation for six months, facilities engineers were familiar with the correct meter to install and were looking for more opportunities to add them to new projects.

6) **Energy meters can be a positive NPV investment.** Even with very conservative estimates of energy savings potential from electric meters, the energy savings from many buildings can quickly repay the costs of installing a meter.

8.4 Going Forward

Literature on energy conservation shows a strong link between feedback of energy usage information and a resulting decrease in energy usage. This body of research assumes that meters are already installed, collecting data, and the only challenge is returning useful information to end users. When meters are not yet installed, there is the additional hurdle of capital investment. However, with analysis of electricity prices, meter cost, and building parameters, meters can be a very attractive investment, even with very conservative estimates for energy savings and high hurdle rates. Once meters are in place collecting data, they can be used in a number of effective ways in addition to behavior change through feedback that ultimately reduce energy use. Energy data can provide insight into maintenance issues through anomalies in usage, provide a check on utility bills, and be used to develop a baseline for typical energy use for buildings. Bringing the information into the organization, energy data can be incorporated into performance metrics for individuals and departments, truly focusing the organization on energy use that was virtually invisible before effective energy metering. Energy information can create significant improvements in the way energy is understood and consumed, and the first step in that process is a positive NPV capital investment in energy meters.

9 Chapter 9: References

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